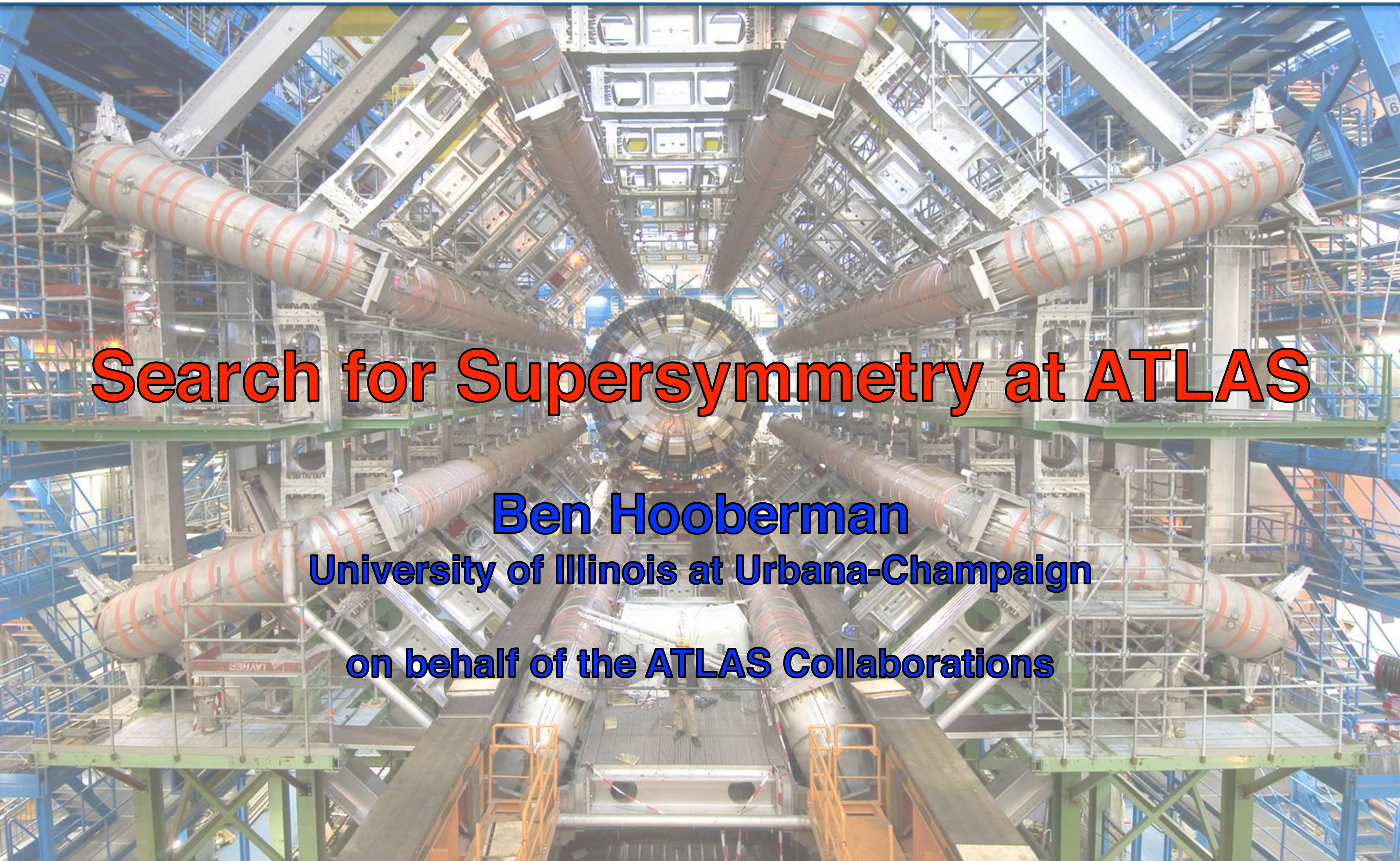


Search for Supersymmetry at ATLAS

Ben Hooberman
University of Illinois at Urbana-Champaign

on behalf of the ATLAS Collaborations

Executive Summary

Executive Summary

"We [still] haven't found it."

~T. Lari, SUSY15

Executive Summary

"We [still] haven't found it."

~T. Lari, SUSY15

but we have some new ideas…

Executive Summary

"We [still] haven't found it."

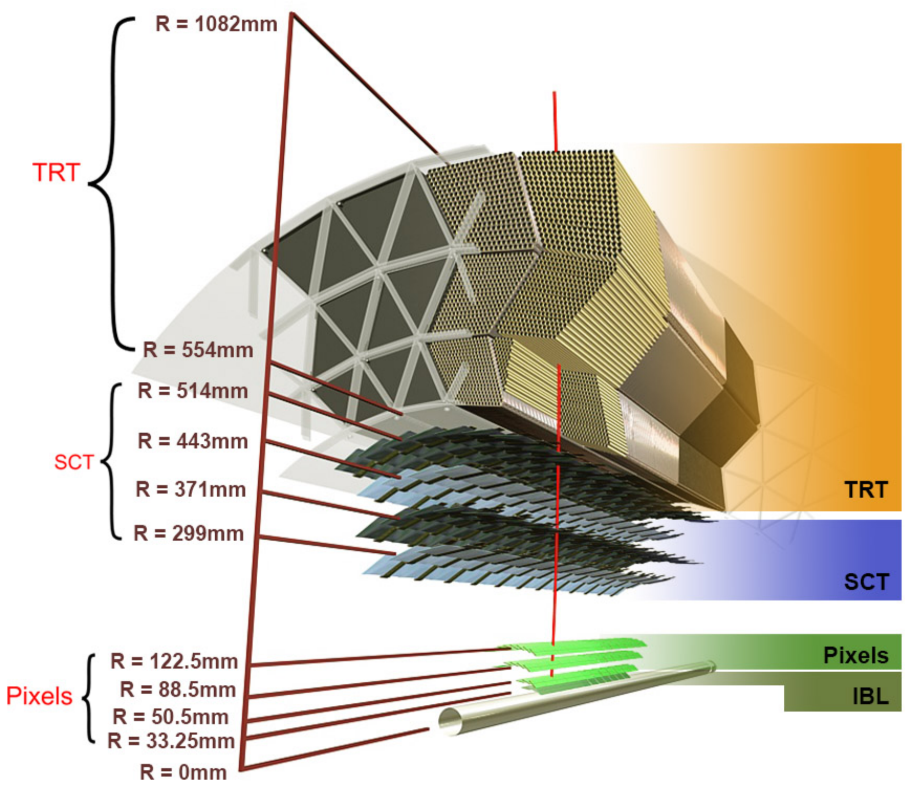
~T. Lari, SUSY15

but we have some new ideas…

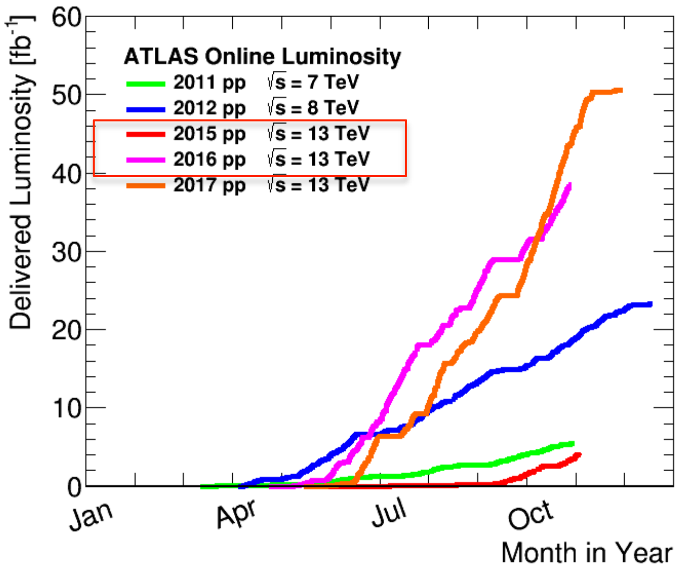
and we're just starting to probe some interesting new territory…

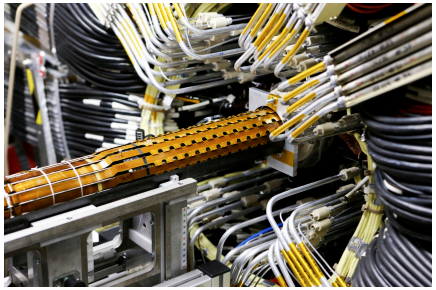
ATLAS Detector & Data Sample

ATLAS Inner Detector



integrated luminosity vs. time





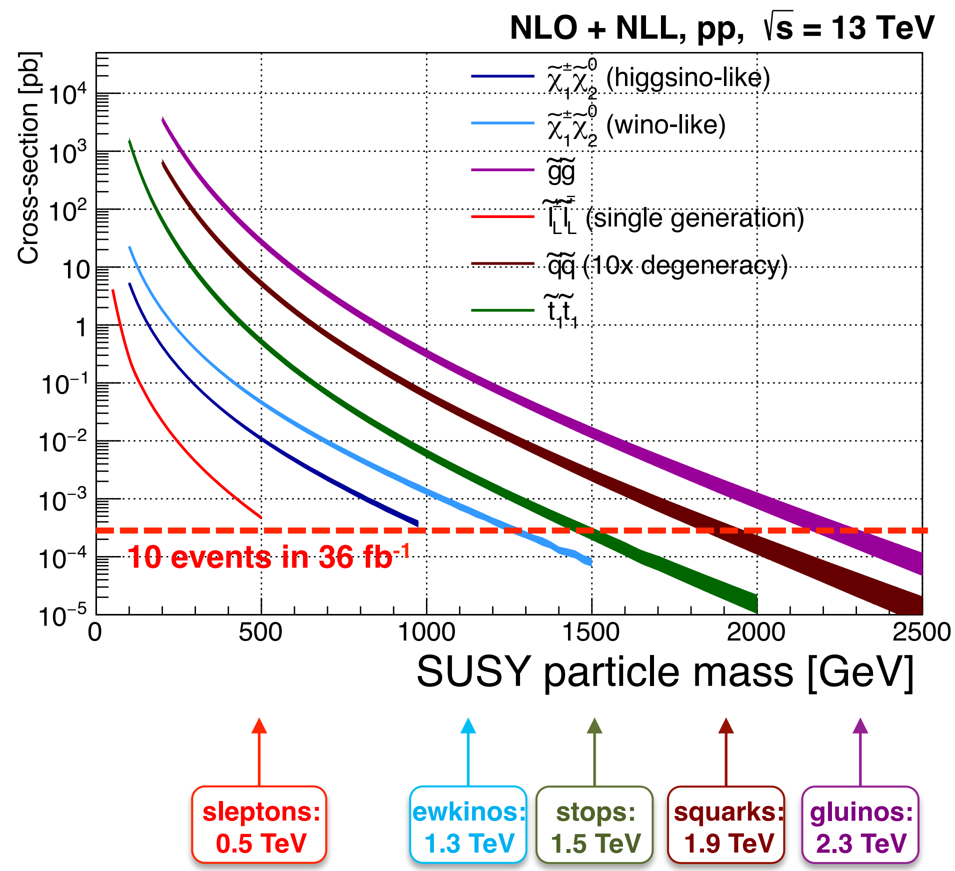
Insertable B-layer:
improved tracking
& flavor-tagging

- Showing results with **36 fb^{-1} 13 TeV 2015+2016 data** (~10× more than SUSY16!)
  - 26 SUSY results with full dataset → **7 brand new for SUSY17!**

- Program of searches for **R-parity conserving SUSY** with **large E_T^{miss}**
- Probe **R-parity violating SUSY** with **high jet / lepton multiplicities or resonances**
- Search for **long-lived particles** using specialized techniques **(e.g. disappearing tracks and displaced vertices)**
- Emphasis on **natural SUSY:** **gluinos, stops, sbottom$_L$, higgsinos***

*3 new results for SUSY17!

SUSY particle cross sections

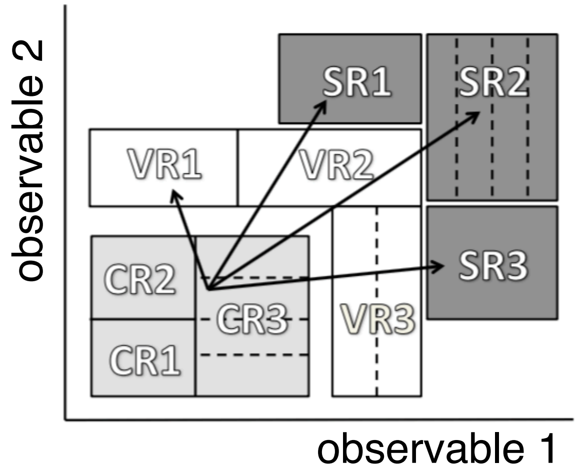


maximum mass reach in 36 fb^{-1} 13 TeV data

Reconstruction & Background Estimation

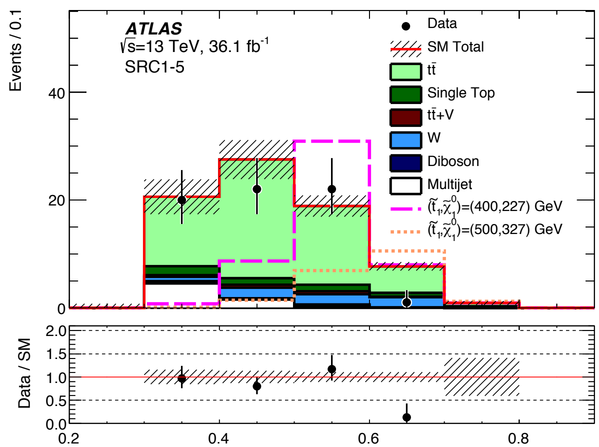
- **Background estimation methods**
  - **MC normalized in data control regions:** for irreducible backgrounds, e.g. ttbar, VV
  - **Data-driven estimates:** for detector / instrumental effects, e.g. instrumental E_T^{miss}, fake / non-prompt leptons
  - **Raw MC:** for rare backgrounds, e.g. ttZ, VVV

background estimation



- **Some recent updates & improvements**
  - Exploit IBL for long-lived particles
  - Recursive Jigsaw Reconstruction (RJR) [1]
  - Reduced lepton thresholds: $p_T(e/\mu) > 4.5$ / 4 GeV
  - Multi-bin shape fits

RJR for hidden stops*



$$R_{\rm ISR} \equiv \frac{E_{\rm T}^{\rm miss}}{p_{\rm T}^{\rm ISR}} \sim \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{t}}}.$$

*$m_{stop} = m_{top} + m_{LSP}$

see parallel talk:
Kouta Onagi: reconstruction techniques

[1] Rogan, Jackson, Santoni, PRD 95, 035031 (2017)

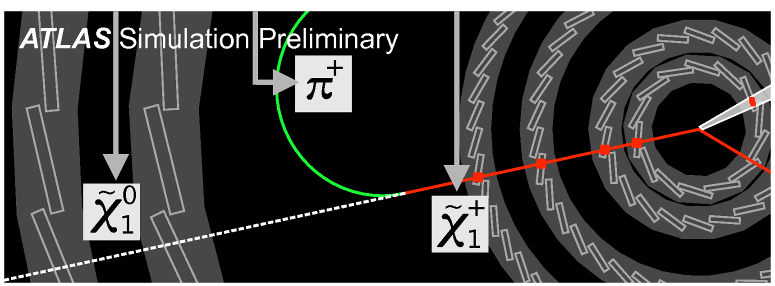
Outline

- Long-lived particles
- R-parity conserving SUSY
  – Electroweak production
  – 3rd generation squarks
  – Inclusive squarks / gluinos
- R-parity violating SUSY

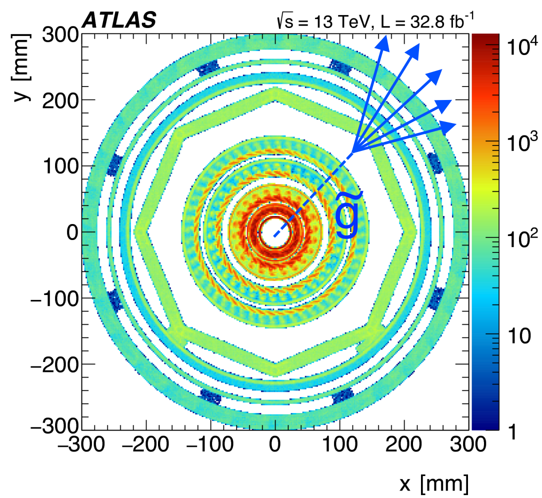
Searches for Long-lived Particles

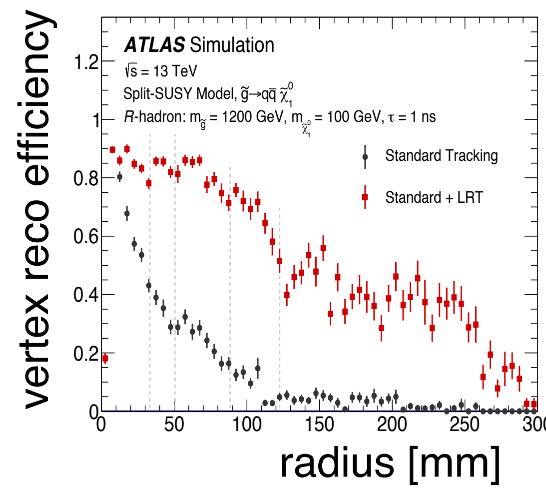
Search	Final State	Sensitivity	References
Direct search for charged LLPs	**disappearing track + E_T^{miss}** + 1 / 4 jets (ISR / gluino decays)	exclude $m(\tilde{\chi}_1^{\pm}) < 460$ GeV for $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 160$ MeV	1712.02118
Search for LLP decay products	**displaced vertex** ($\geq$5 tracks) **+ E_T^{miss}**	probe 1.8 - 2.4 TeV gluinos with $\tau \sim O(10^{-2})$ - $O(10)$ ns	1710.04901

disappearing track



displaced vertex

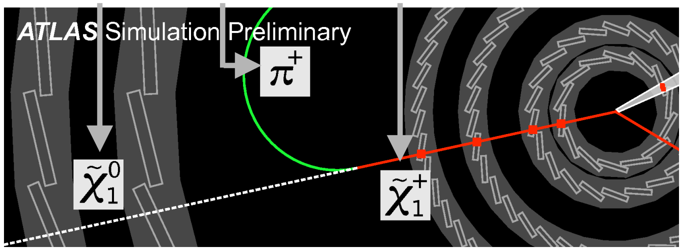


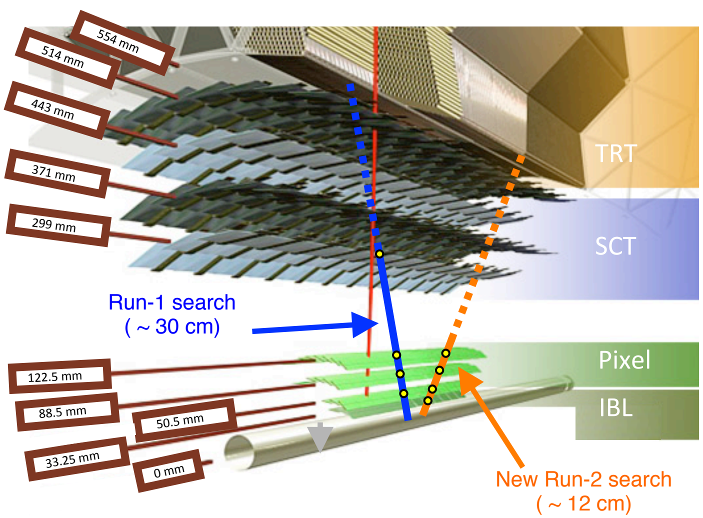


Large Radius Tracking
[ATL-PHYS-PUB-2017-014]

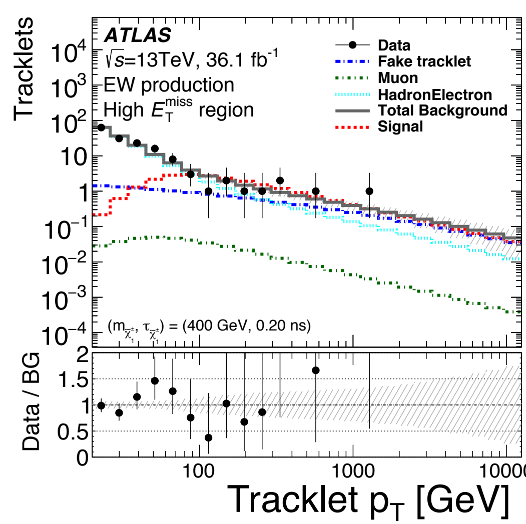
see parallel talks:
Larry Lee: RPV / long-lived squarks/gluinos
Joey Reichert: disappearing track

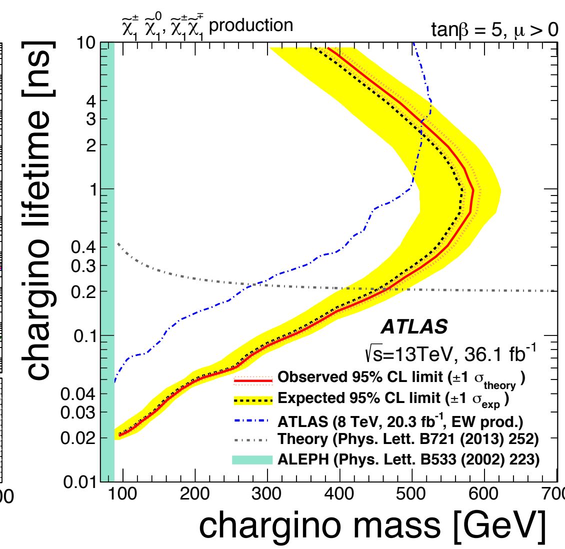
Disappearing Track Search





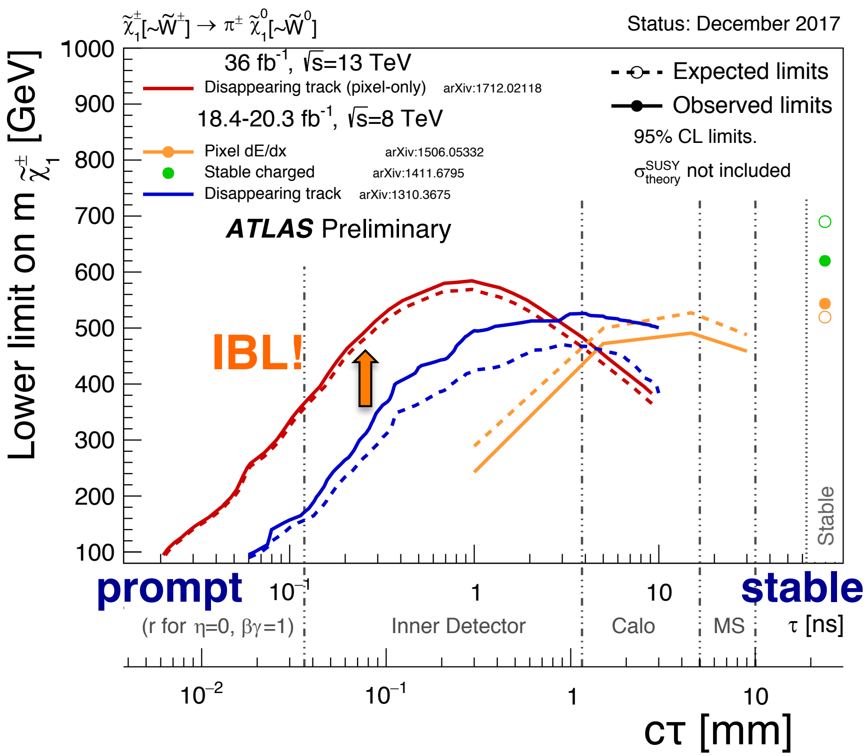
- **Search for long-lived charged particles leading to disappearing track + MET**
- e.g. for pure wino-like $\tilde{\chi}_1^\pm$ / $\tilde{\chi}_1^0$
  – $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim 160$ MeV → cτ ~ 6 cm (0.2 ns)
- Pixel-only tracklets with IBL reduce minimum track length to 12 cm (from 30 cm in Run-I)
- **Exclude pure winos up to 460 GeV**
  – Also sensitive to higgsinos…



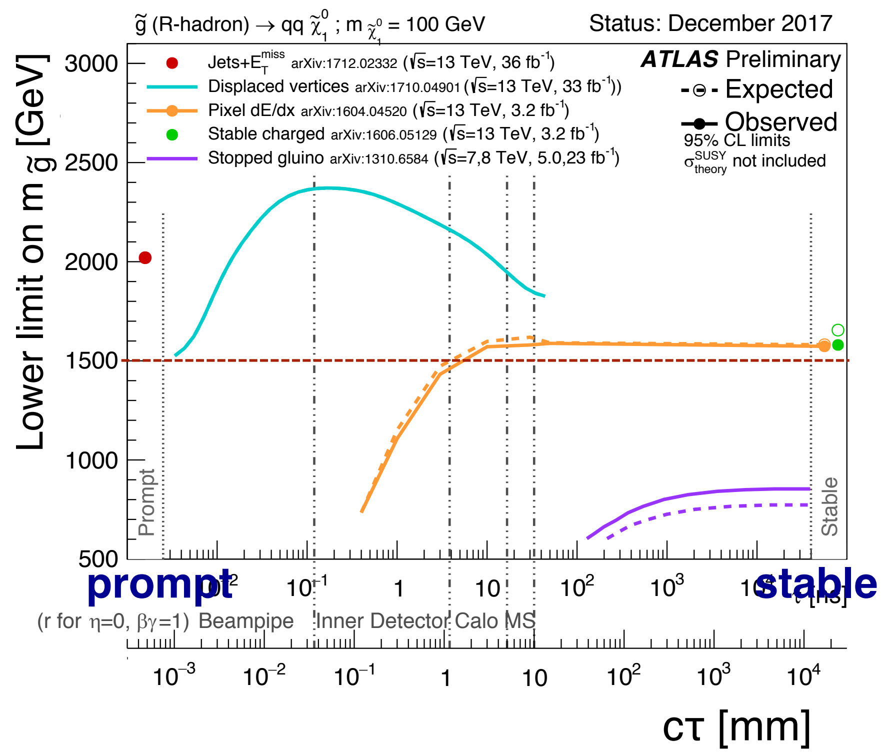


Summary of Long-Lived Searches

long-lived charginos



long-lived gluinos



significant improvement at low cτ from IBL

gluinos up to 1.5 TeV excluded over full range*

*assuming m_{LSP} = 100 GeV

RPC Electroweak Production

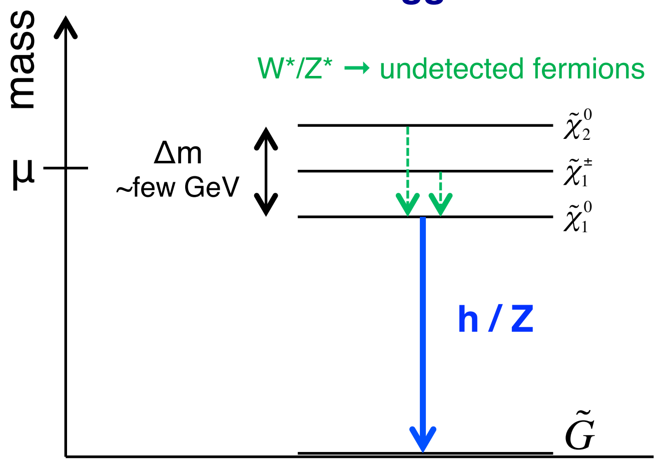
Search	Final State	Limits	References
ewkino 2ℓ / 3ℓ	2/3 leptons + MET	max. reach $m_{N2/C1}$ ~ 1150 GeV (light sleptons), $m_{N2/C1}$ ~ 580 GeV (no light sleptons)	ATLAS-CONF-2017-039
ewkino $2\tau_{had}$	$2\tau_{had}$ + MET	$m_{N2/C1}$ ~ 580 GeV (light staus)	1708.07875
ewkino 4ℓ [13 fb^{-1}]	4ℓ ($\leq 2\tau_{had}$) + (MET or m_{eff})	probe up to 1.1 TeV RPV winos	ATLAS-CONF-2016-075
NEW compressed higgsino LSPs	soft e^+e^- / $\mu^+\mu^-$ + jet(s) + MET	μ > 100 (130) GeV for $\Delta m(\tilde{\chi}^0_2, \tilde{\chi}^0_1)$ = 3 (5) GeV	SUSY-2016-25
compressed slepton NLSPs	soft $\ell^+\ell^-$ + jet(s) + MET	$m_{\tilde{\ell}}$ > 70 (180) GeV for $\Delta m(\tilde{\ell}, \tilde{\chi}^0_1)$ = 1 (5) GeV	
NEW GMSB higgsino NLSPs	4b + MET	exclude μ between 130-230 GeV and 290-880 GeV for BF($\tilde{h} \rightarrow h \tilde{G}$) = 1	ATLAS-CONF-2017-081
NEW ultra-compressed higgsinos	disappearing track + jet + MET	exclude charged higgsinos up to 152 GeV	ATL-PHYS-PUB-2017-019 (reinterpretation of 1712.02118)
NEW GMSB with photons	γ / γγ + MET	probe up to 1.2 TeV charginos/neutralinos	ATLAS-CONF-2017-080

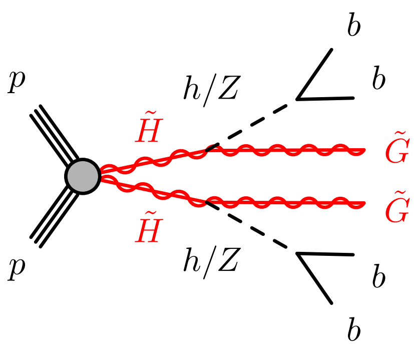
- 8 results → 4 new for SUSY17, **including first 3 ATLAS higgsino searches!**

see talks:
Joey Reichert: higgsinos
Christian Sander: gauginos/sleptons
Alex Mann: GMSB
Henning Flaecher: DM at LHC

- Key for naturalness
- Extremely challenging at hadron colliders

Scenario 1
GMSB higgsino NLSP





hh / hZ / ZZ +MET

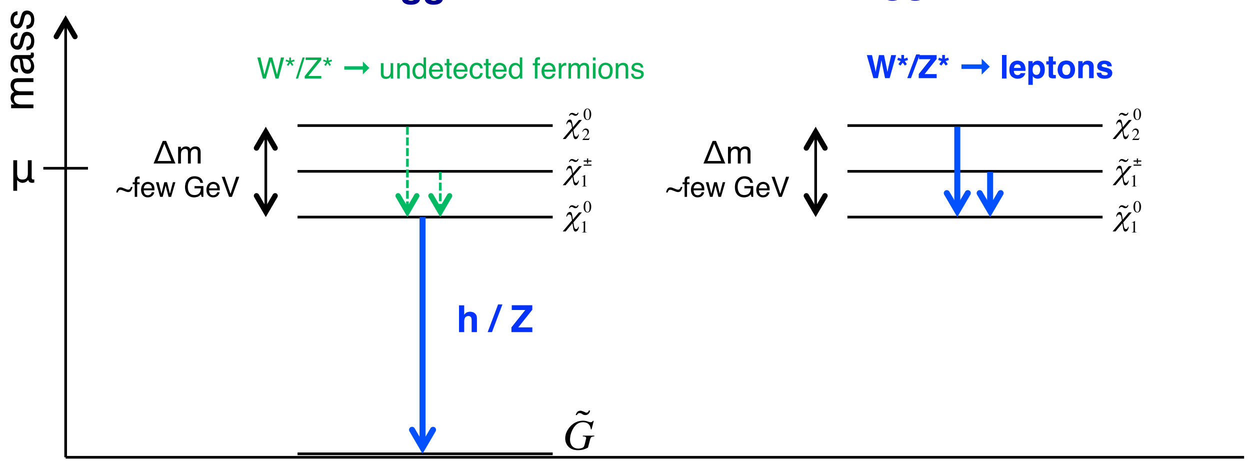
NEW

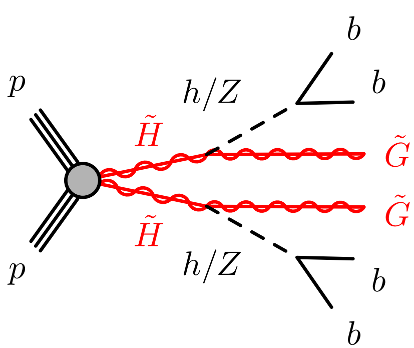
hh→4b
ATLAS-CONF-2017-081

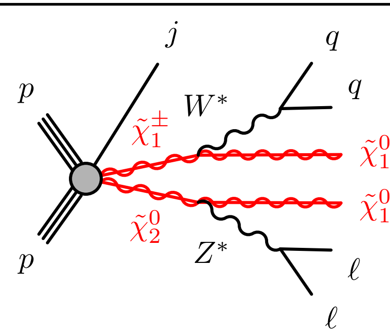
Higgsino Searches

Scenario 1
GMSB higgsino NLSP

Scenario 2:
higgsino LSP







hh / hZ / ZZ +MET

soft $\ell^+\ell^-$ + jet(s) + MET

NEW **hh→4b** ATLAS-CONF-2017-081

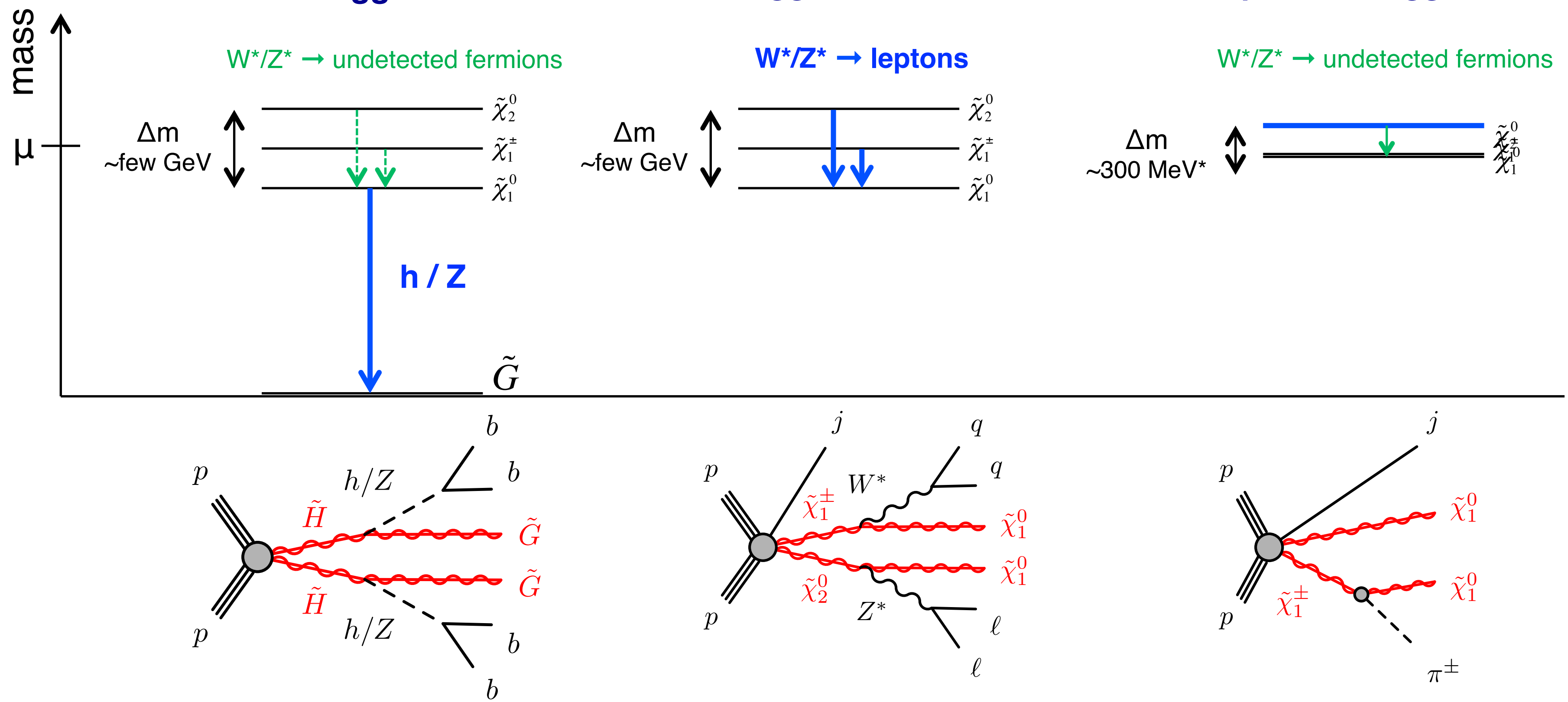
NEW **compressed ewkinos** SUSY-16-025

Higgsino Searches

Scenario 1 — **GMSB higgsino NLSP**

Scenario 2: — **higgsino LSP**

Scenario 3: — **ultra-compressed higgsino LSP**



hh / hZ / ZZ +MET | **soft $\ell^+\ell^-$ + jet(s) + MET** | **disappearing track**

NEW **hh→4b** ATLAS-CONF-2017-081

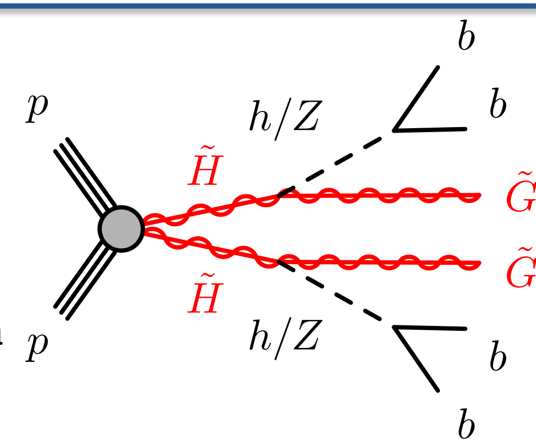
NEW **compressed ewkinos** SUSY-16-025

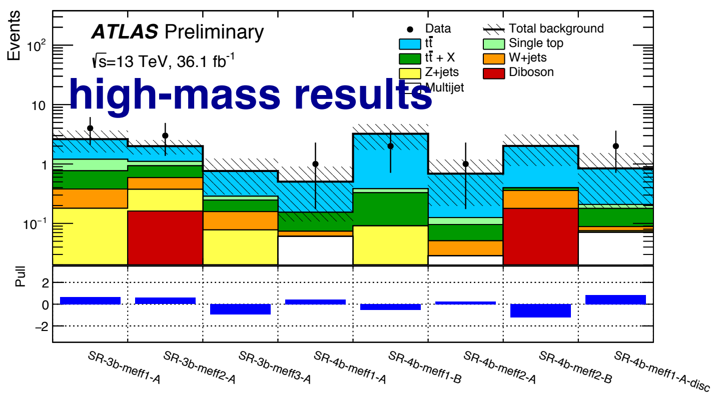
NEW **disappearing higgsinos (reinterpretation)** ATL-PHYS-PUB-2017-019

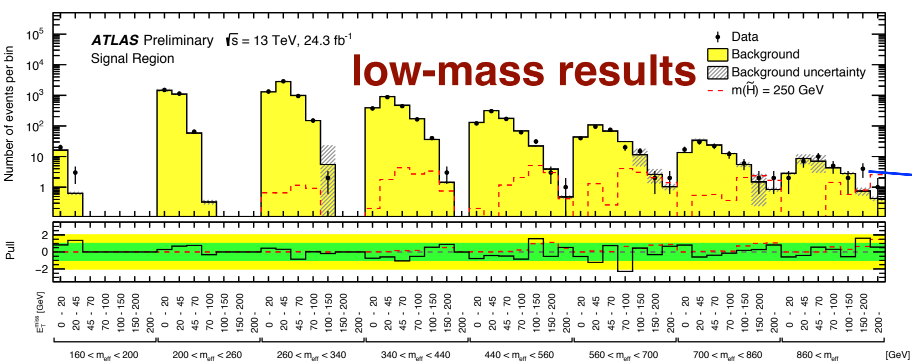
*Fukuda, Nagata, Otono, Shirai, arXiv:1703.09675 [hep-ph]

Scenario 1: GMSB higgsino NLSP
hh → 4b+MET

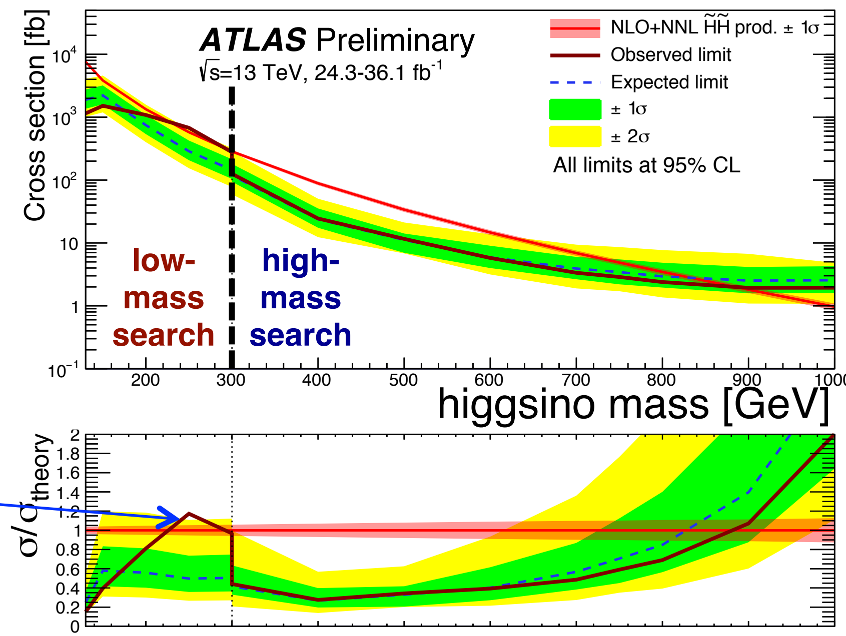
- Select events with ≥4 jets (≥3 b-tagged) + E_T^{miss}
- **High-mass search (μ > 300 GeV)**
  - Trigger on large E_T^{miss}, estimate backgrounds from MC
- **Low-mass search (μ < 300 GeV)***
  - Use b-jet triggers to probe low E_T^{miss}, extrapolate bkg from 2b data







56 exclusive (MET,m_{eff}) bins

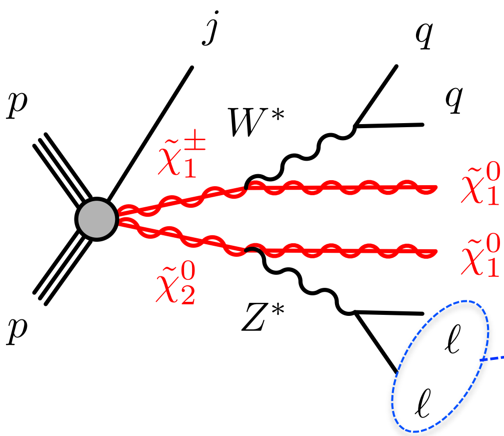


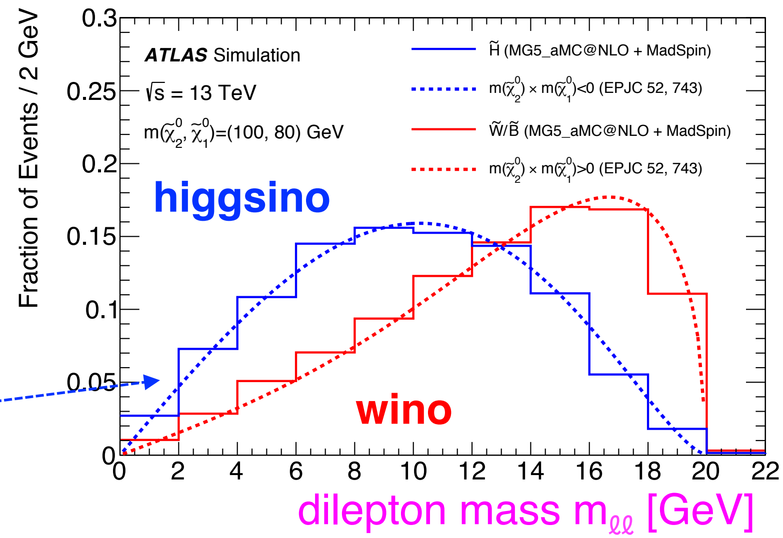
max. excess
4 vs. 1.0 ± 0.2

*extension of ATLAS di-Higgs search, see parallel talk Elizabeth Brost

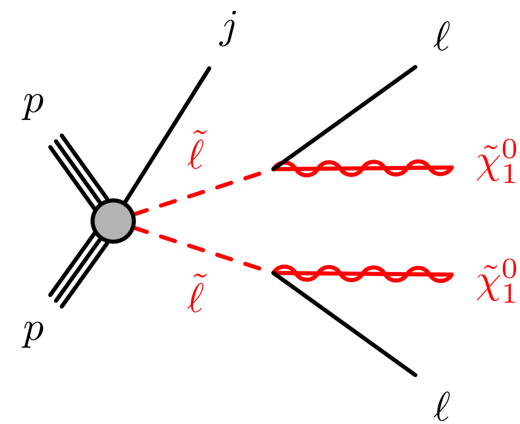
Scenario 2: Compressed Higgsino / Slepton

higgsinos

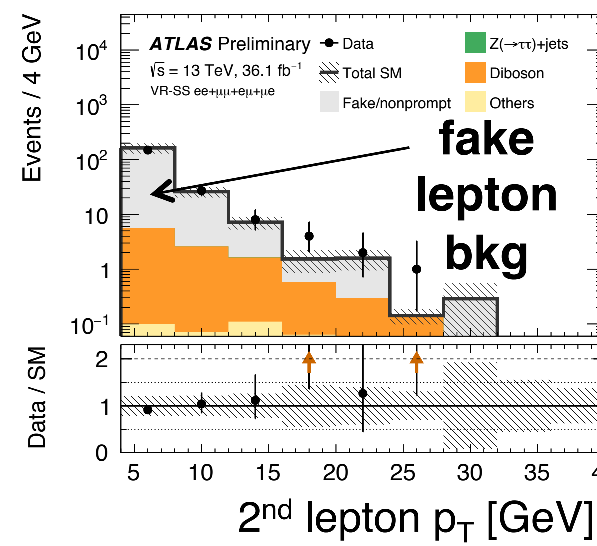




sleptons



same-sign 2ℓ

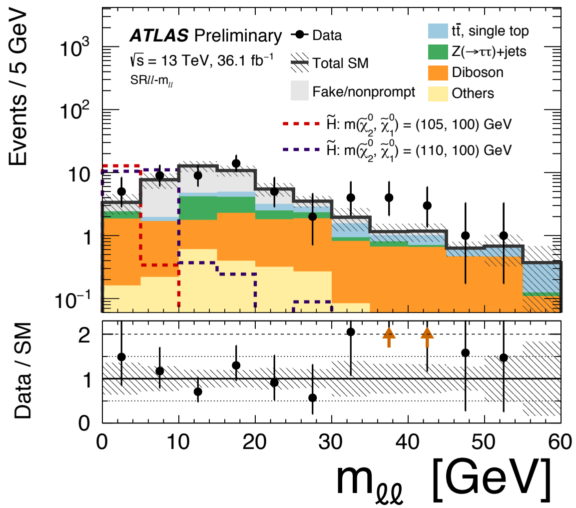


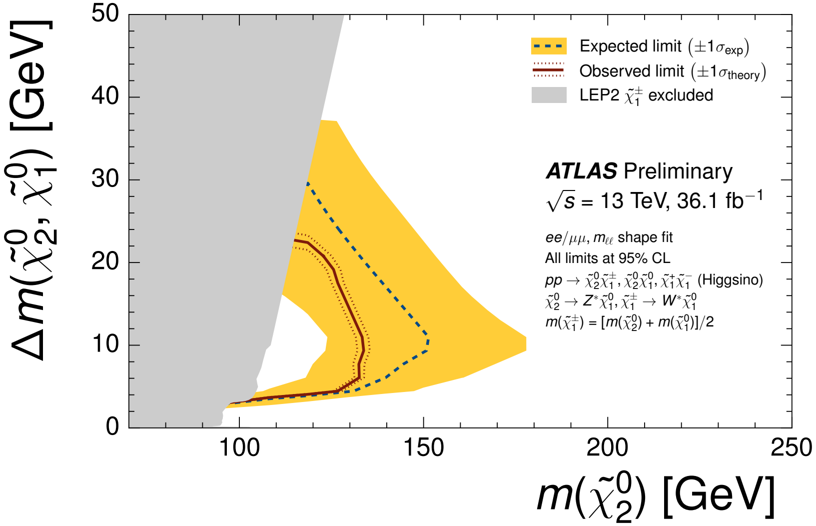
- Search for direct production of higgsinos using $m_{\ell\ell}$
- Search for compressed slepton+LSP using $M_{T2}(\ell\ell)$
- **Soft leptons drive the sensitivity**
  - Lowest electron p_T thresholds ever used in ATLAS! $p_T(\ell_2) > 4.5$ / 4 GeV e/μ, $m_{\ell\ell} > 1$ GeV (veto 3.0-3.2)
  - ***Robust fake lepton modeling is key*** ⟶
- Highly-optimized selections

Higgsinos & Sleptons

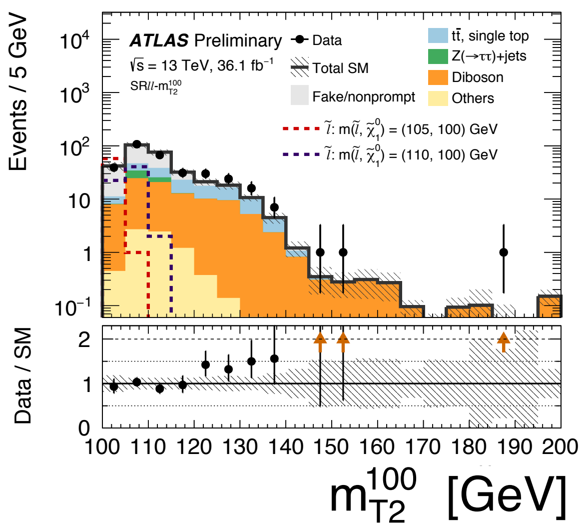
probing territory beyond LEP!

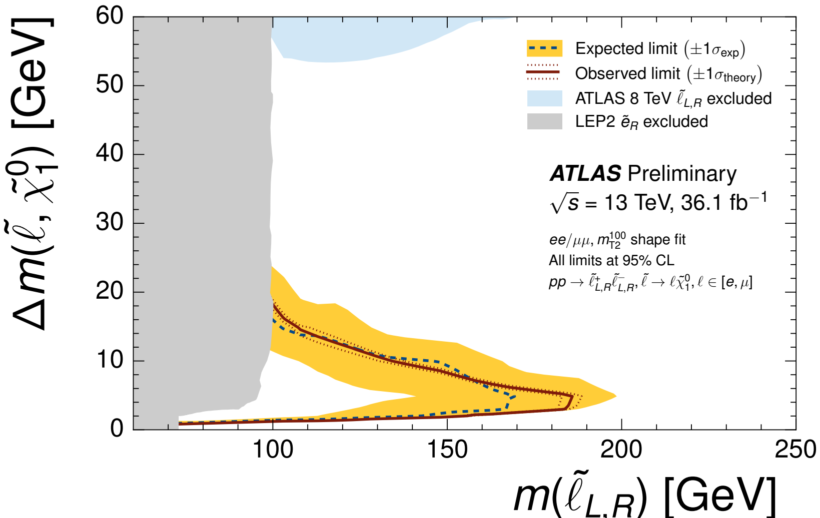
higgsinos





sleptons

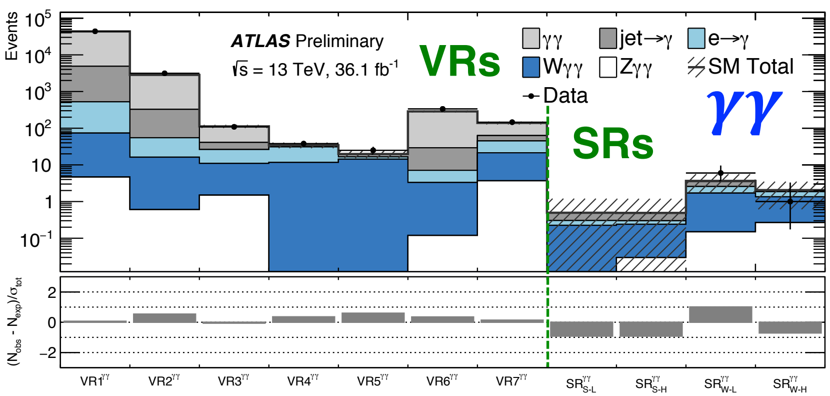


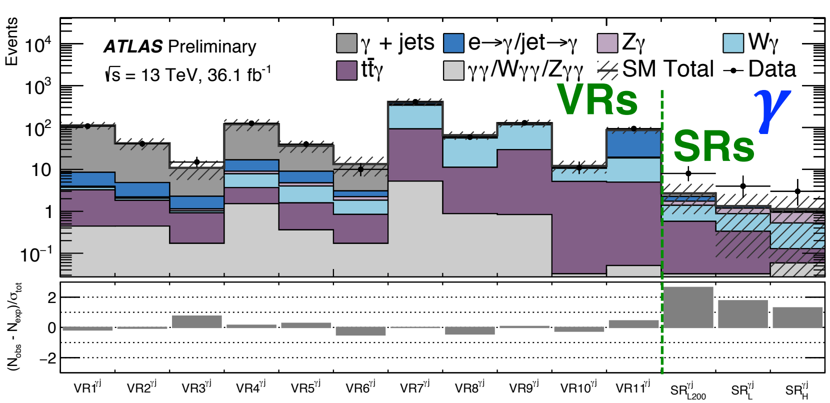


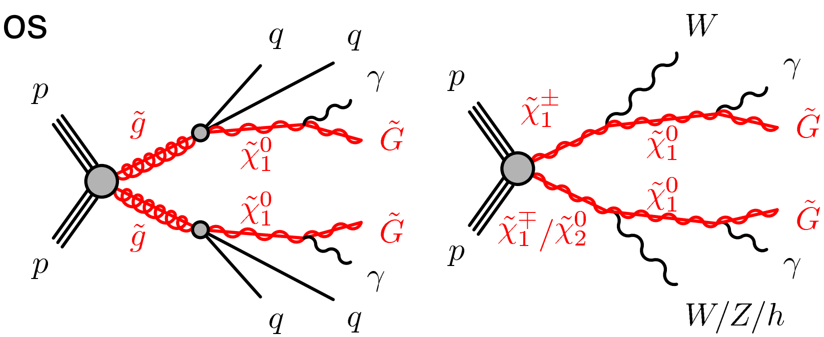
additional interpretations for winos and NUHM2 (in backup)

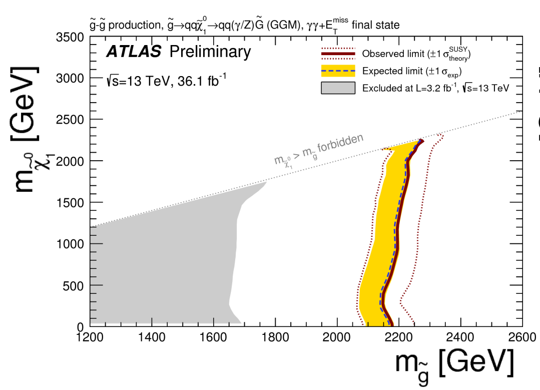
GMSB with photons

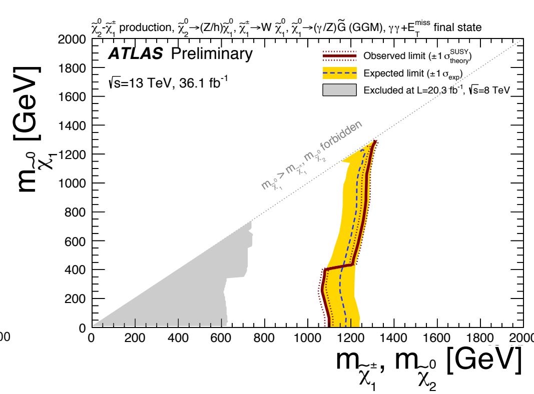
- **γ / γγ + MET + jets → strong production**
  - Probe up to 2.2 TeV gluinos / 1.8 TeV squarks
- **γ / γγ + MET → electroweak production**
  - Probe up to 1.2 TeV charginos/neutralinos





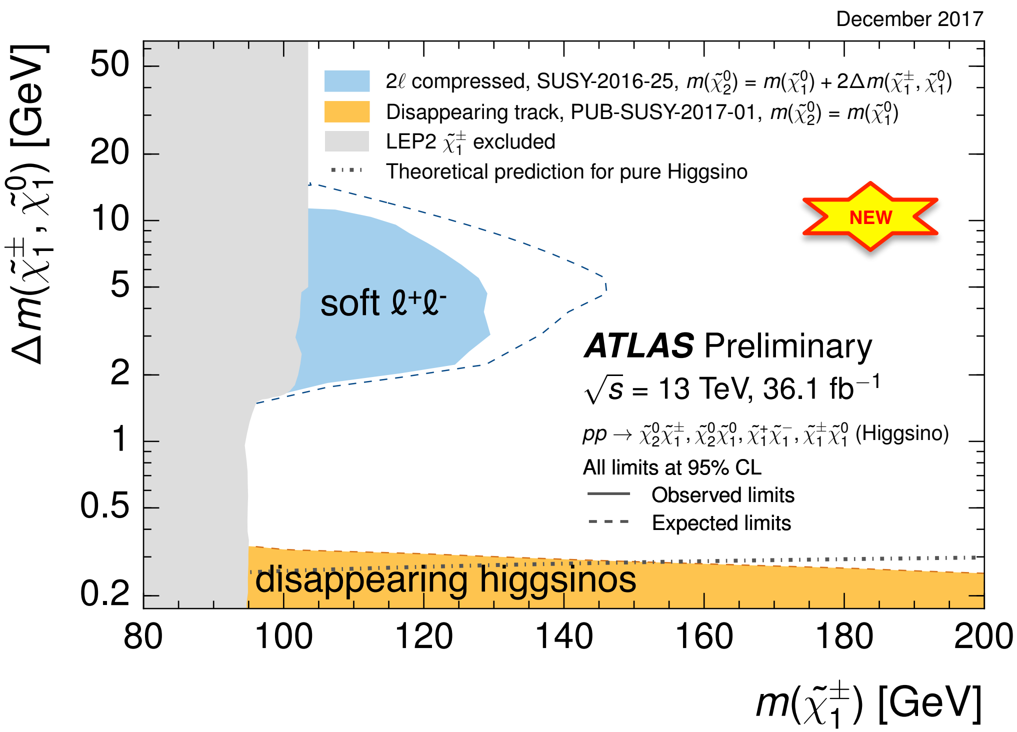






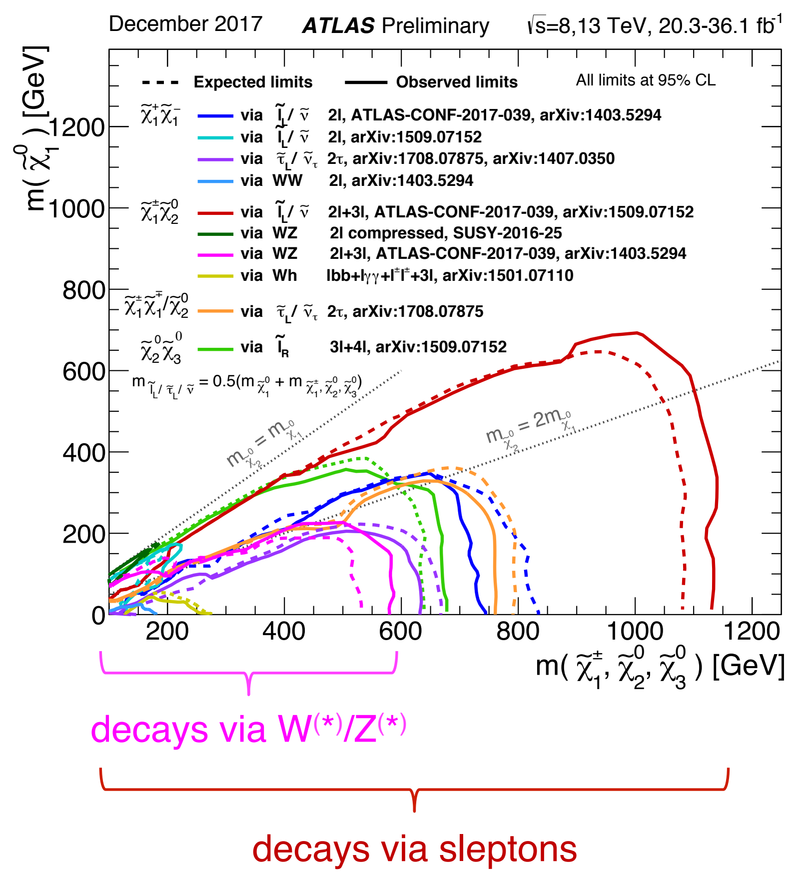
Signal Region	N_{obs}	N_{exp}^{SM}	S_{obs}^{95}	S_{exp}^{95}	$\langle\epsilon\sigma\rangle_{obs}^{95}$ [fb]	$\langle\epsilon\sigma\rangle_{exp}^{95}$ [fb]	$Z\ (p)$
$SR_{L200}^{\gamma j}$	8	$2.68^{+0.64}_{-0.63}$	11.5	$5.4^{+2.2}_{-1.2}$	0.318	$0.151^{+0.060}_{-0.033}$	2.36 (0.009)

higgsinos



probing territory beyond LEP!

winos



RPC 3rd generation Searches

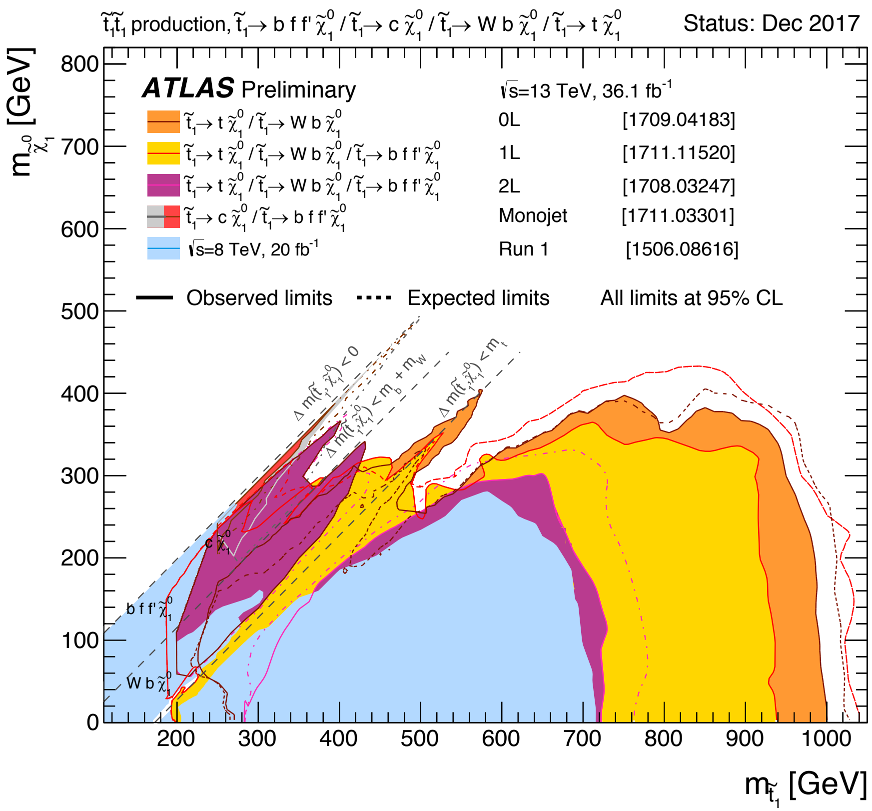
Search	Final State	Max Mass Reach [GeV]	References
sbottom	2 b-jets + MET	950 GeV (stop) 860 GeV (sbottom)	1708.09266
stop 0L	0ℓ + b-jets + MET	950 GeV	1709.04183
stop 1ℓ with DM+HF	1ℓ + jets + MET	950 GeV	1711.11520
stop 2ℓ	2ℓ + MET (+ jets)	720 GeV	1708.03247
stops with Z/h	1 / 2 / 3ℓ+ b-jets + MET	870 GeV	JHEP08 (2017) 006
NEW **stop→stau**	2ℓ + MET (+ jets)	1160 GeV	ATLAS-CONF-2017-079

- 6 results including **1 new result for SUSY17**

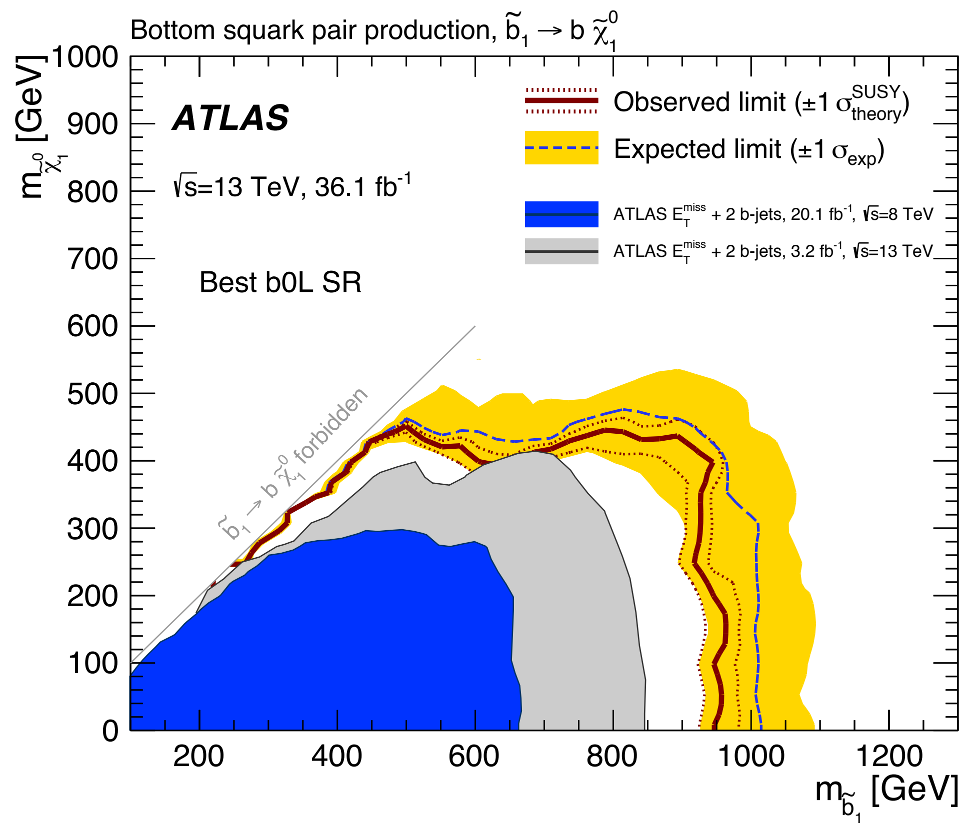
see parallel talks:
Sara Strandberg: stops/sbottoms
Ian Michael Snyder: pMSSM stop results
Antonia Miucci: stops with taus or Z/h bosons

Summary of ATLAS 3rd Generation Searches

stops

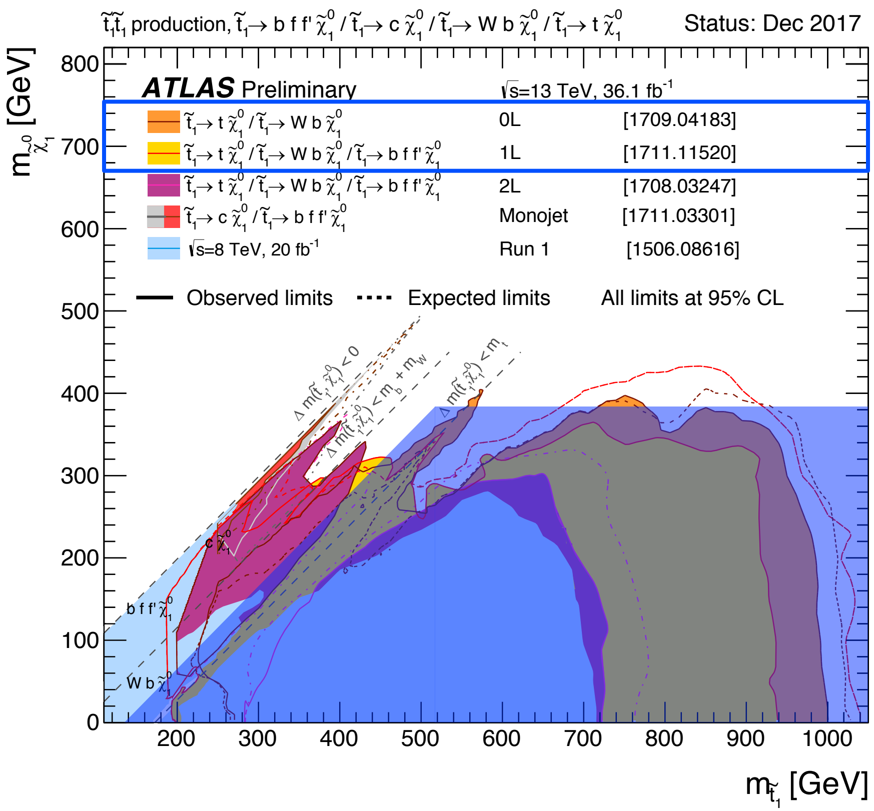


sbottoms

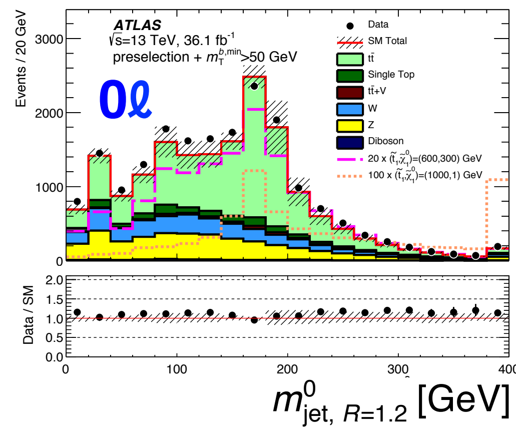


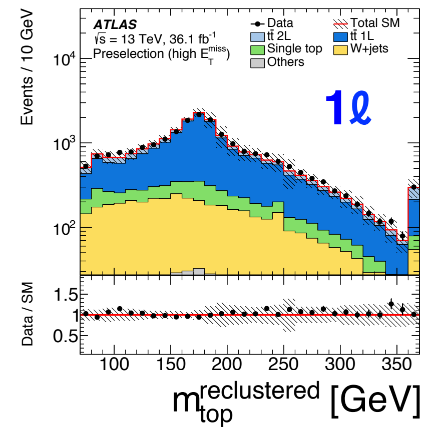
+ additional searches for $\tilde{t}\to b\,\tilde{\chi}_1^\pm$ or $\tilde{b}\to t\,\tilde{\chi}_1^\pm$ and interpretations with full models (pMSSM)

stop 0ℓ and 1ℓ



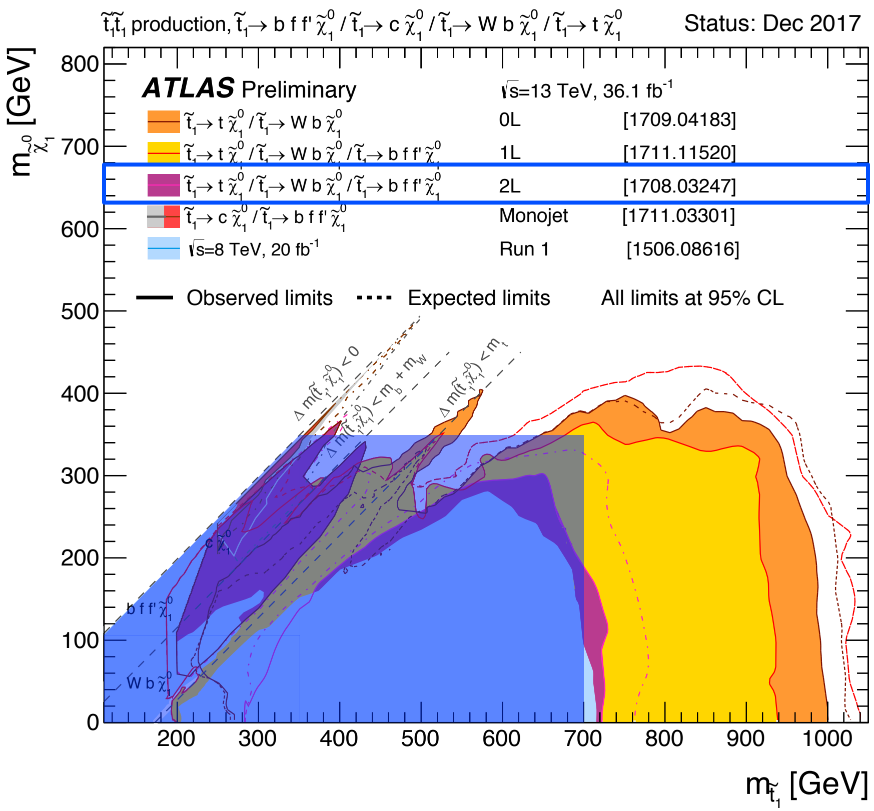
workhorses



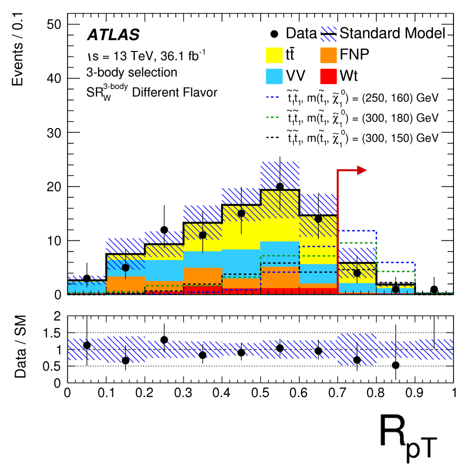


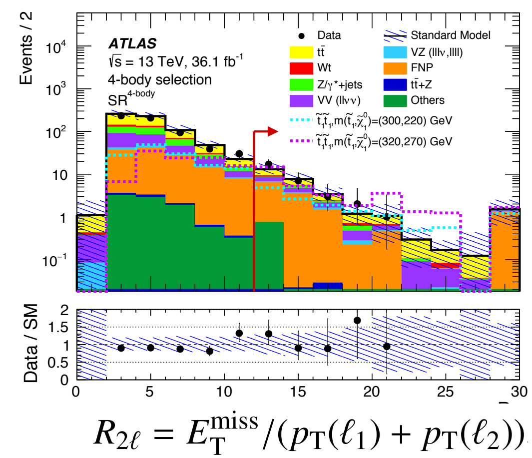
exploit **jet substructure** for hadronic top tagging

stop 2ℓ



exploit novel search variables, including "Super-Razor" [1]





off-shell top

$m_W < \Delta m < m_{top}$

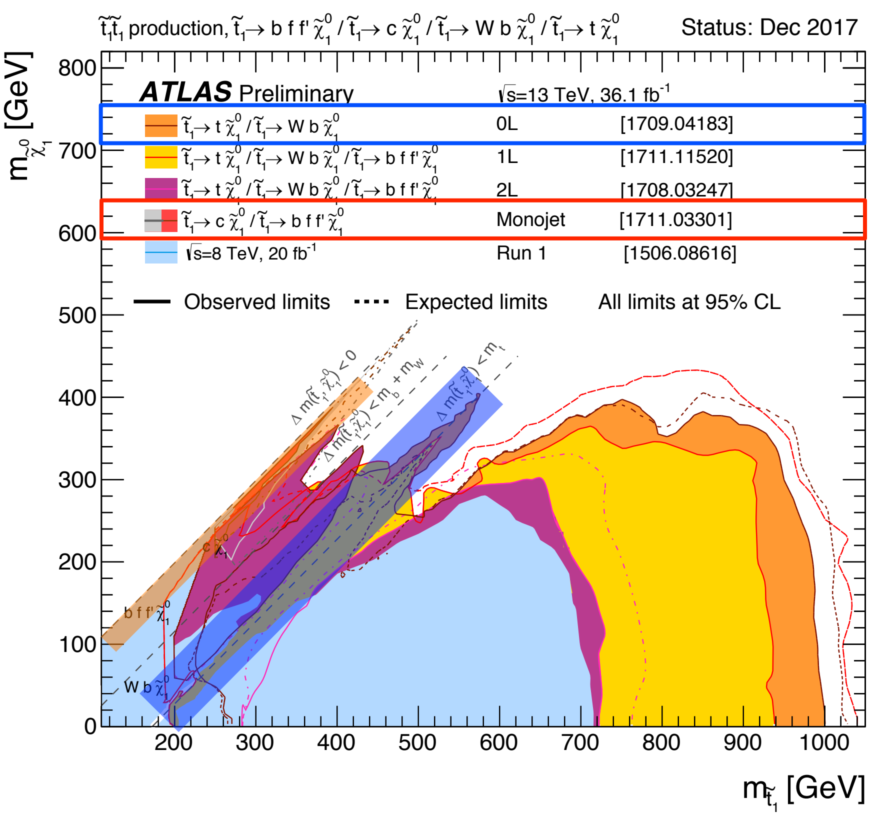
off-shell top and W

$\Delta m < m_W$

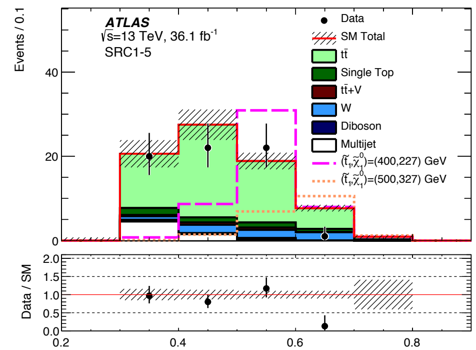
[1] Buckley, Lykken, Rogan, Spiropulu, PRD 89055020, 2014

$\Delta m = m_{stop} - m_{LSP}$

Plugging the Gaps

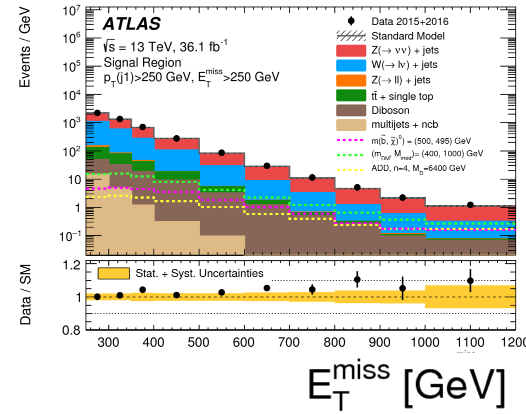


RJR stop 0ℓ

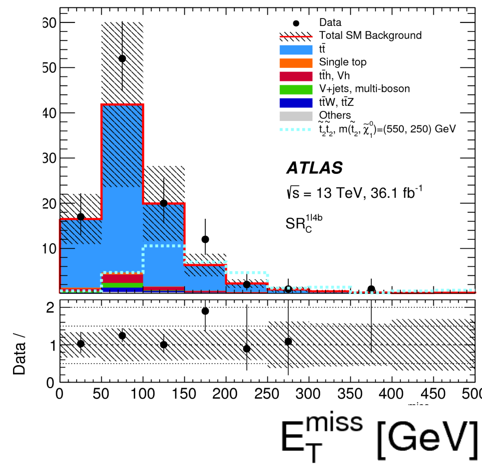


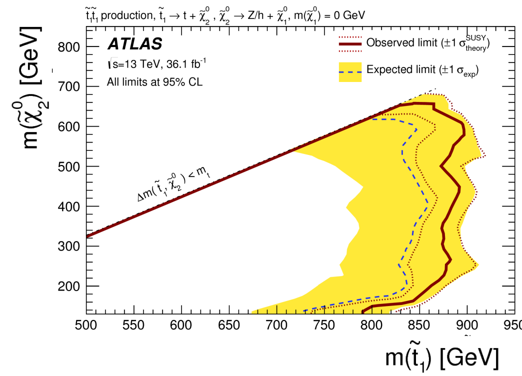
$$R_{\rm ISR} \equiv \frac{E_{\rm T}^{\rm miss}}{p_{\rm T}^{\rm ISR}} \sim \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{t}}}.$$

mono-jet



$stop_2 \to Z/h + stop_1$

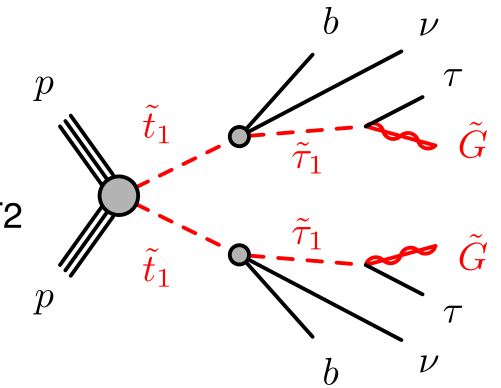


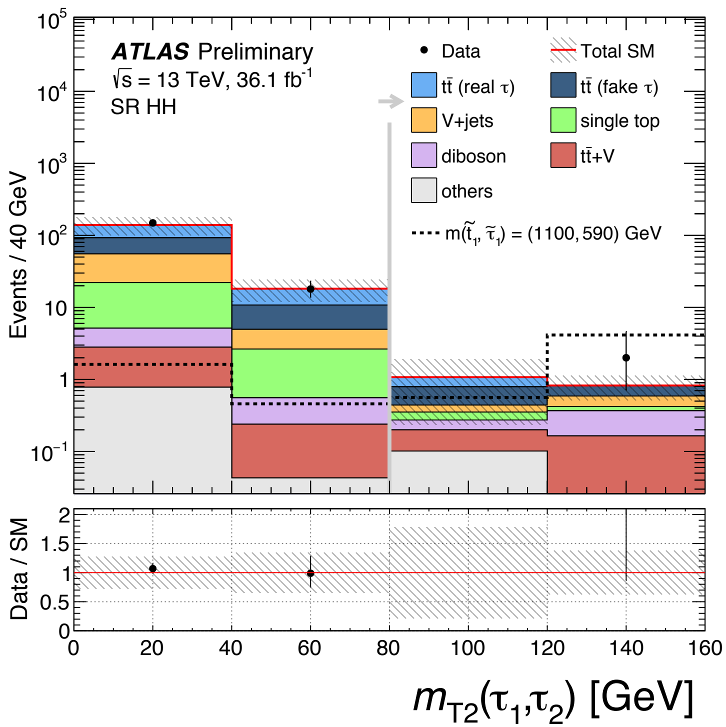


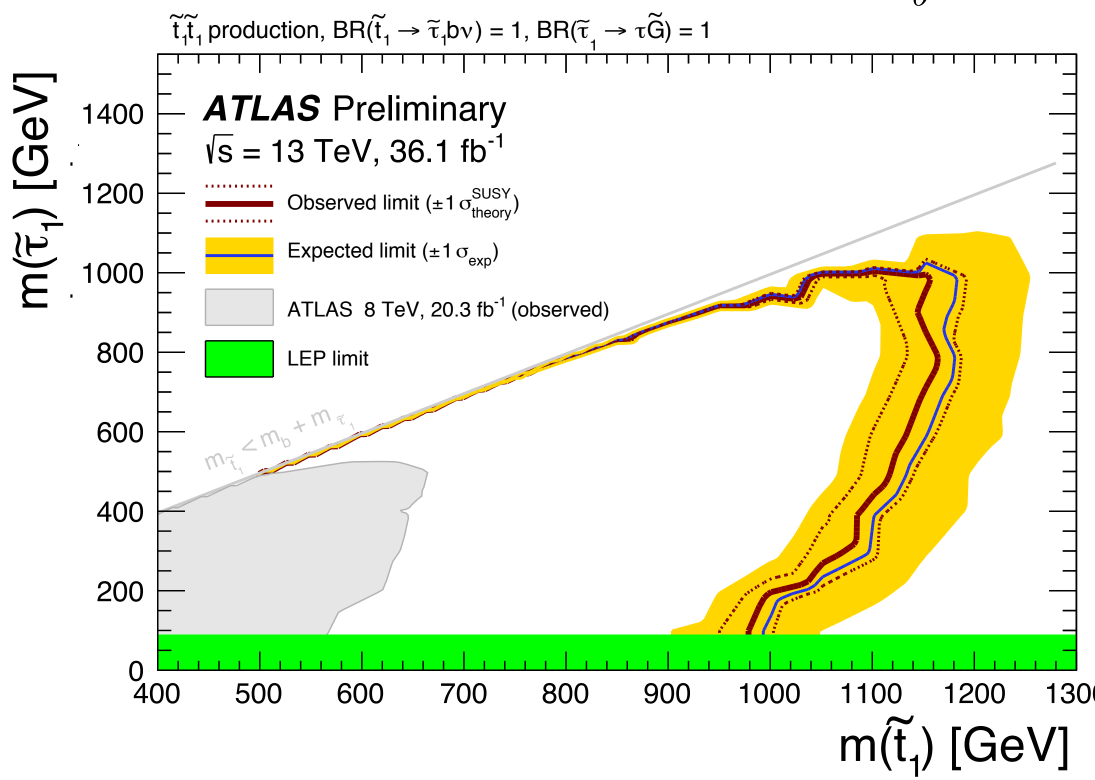
$m_{stop1} = m_{top} + m_{LSP}$

stop→stau Search

- Extend sensitivity to tau-rich models
- Search in $\ell\tau_h$ / $\tau_h\,\tau_h$ channels with large E_T^{miss} and m_{T2}
- Probe up to 1.16 TeV stops







RPC inclusive squark/gluino searches

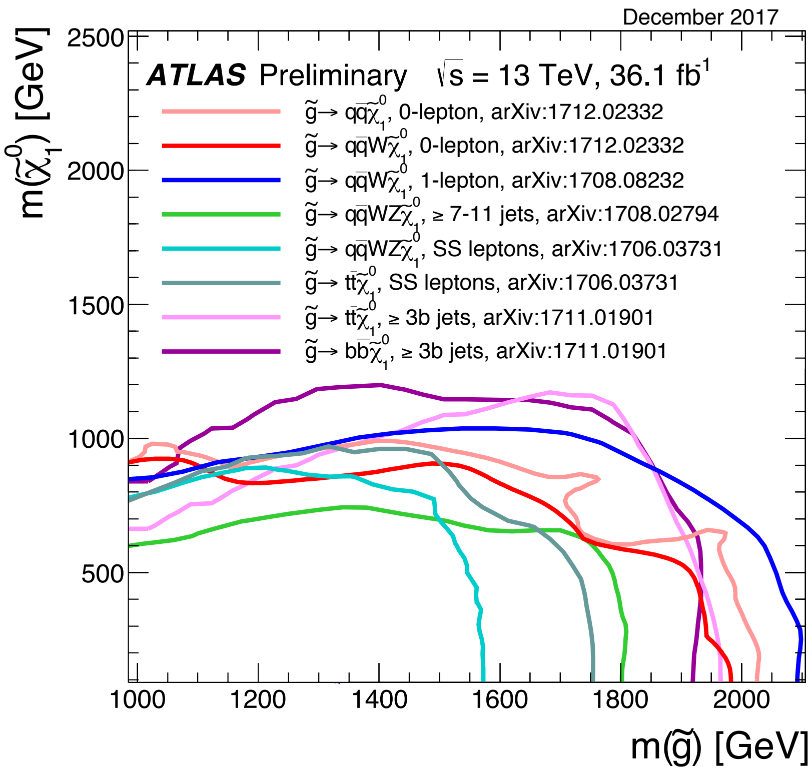
Search	Final State	Maximum Mass Reach	References
0L squarks/gluinos	0 leptons + 2-6 jets + MET	m_{gluino} ~ 2.0 TeV, m_{squark} ~ 1.6 TeV	1712.02332
0L squarks/gluinos	0 leptons + 7-10 jets + MET	m_{gluino} ~ 1.8 TeV	1708.02794
1L squarks/gluinos	1 lepton + jets + MET	m_{gluino} ~ 2.1 TeV, m_{squark} ~ 1.25 TeV	1708.08232
gluinos with t/b	0/1 lepton + 3-4 b-jets + MET	m_{gluino} ~ 2.0 TeV	1711.01901
Z/edge [14.7 fb^{-1}]	2 OS leptons + jets + MET	m_{gluino} ~ 1.7 TeV, m_{squark} ~ 980 GeV	EPJC 77 (2017) 144
SS2L/3L	2 SS leptons/3 leptons	m_{gluino} ~ 1.87 TeV, $m_{sbottom}$ ~ 980 GeV	1706.03731
GMSB with photons NEW	γ / γγ + jets + MET	max. reach up to 1.9 / 2.2 TeV squarks / gluinos	ATLAS-CONF-2017-080

- 7 results with 2016 data, **1 new result for SUSY17**

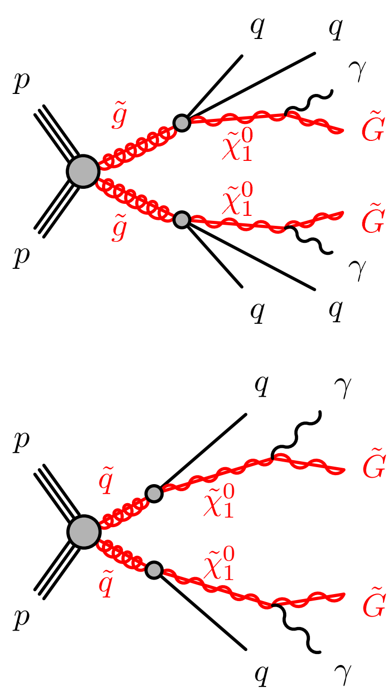
see parallel talks:
Koichi Nagai: all-hadronic squarks/gluinos
Tova Holmes: ≥1ℓ squarks/gluinos
Alex Mann: GMSB

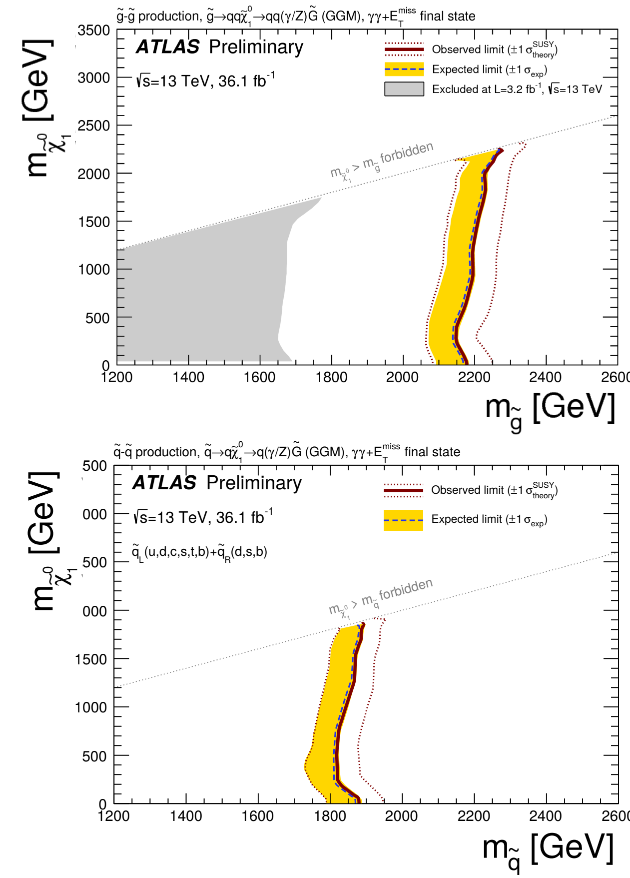
Summary of Inclusive Squark/Gluino Searches

jets + MET + n leptons (n = 0, 1, 2)



jets + MET + m photons (m = 1, 2)





- Probe up to 2.1 TeV gluinos and down to m_{gluino}-m_{LSP} = 100 GeV
- Extend sensitivity to GMSB scenarios → probe up to 1.8 / 2.2 TeV squarks / gluinos

RPV / Long-lived SUSY Searches

NEW

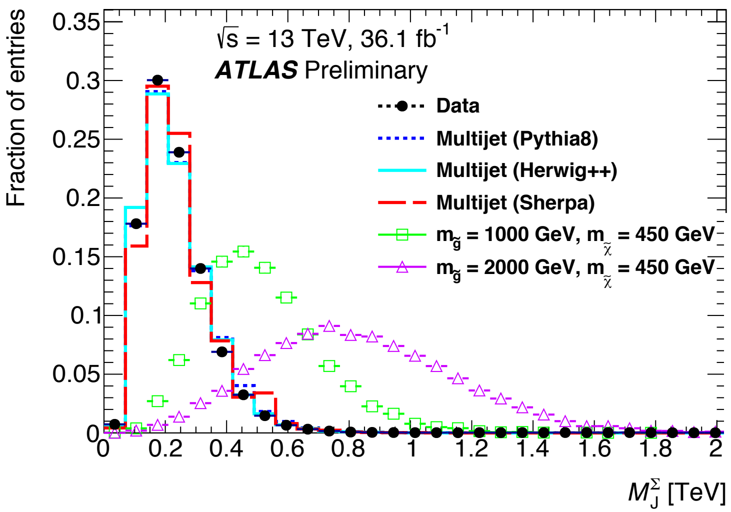
Search	Final State	Maximum Mass Reach	References [1]
RPV multijets	≥4 jets	m_{gluino} ~ 1.9 TeV	SUSY-2016-22
RPV stop→jj	4 jets	m_{stop} ~ 610 GeV	1710.07171
RPV stop→bℓ	2 OS leptons + 2 b-jets	m_{stop} ~ 1.5 TeV	1710.05544
RPV 1L	1 lepton + 8-12 jets + no MET	m_{gluino} ~ 2.1 TeV, m_{stop} ~ 1.1 TeV	1704.08493

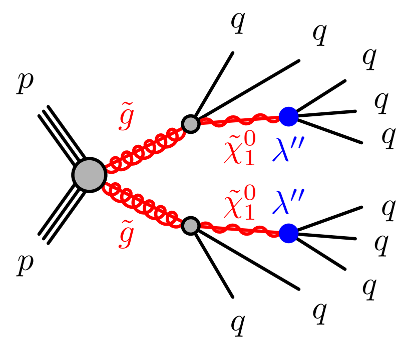
- 4 results including **1 new result for SUSY17 on RPV multi-jets**
  - N.B. RPC SUSY searches can also be sensitive to RPV (E_T^{miss} from neutrinos)

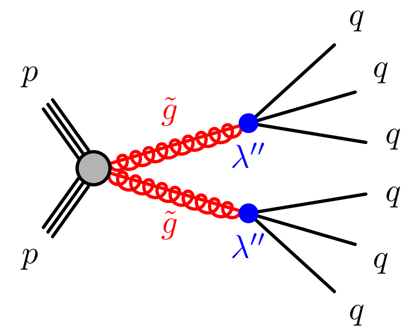
see parallel talks:
Larry Lee: RPV squarks/gluinos
Francesca Ungaro: RPV stops

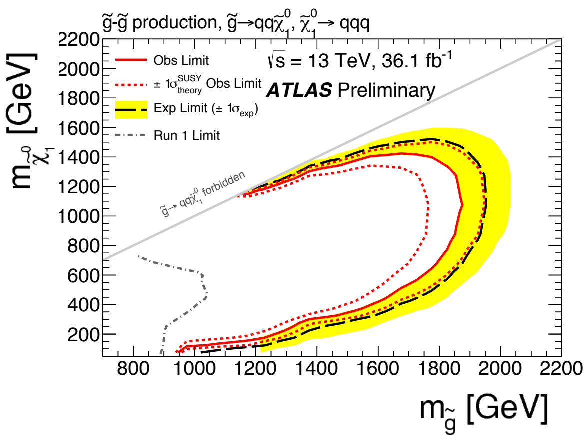
RPV multi-jets

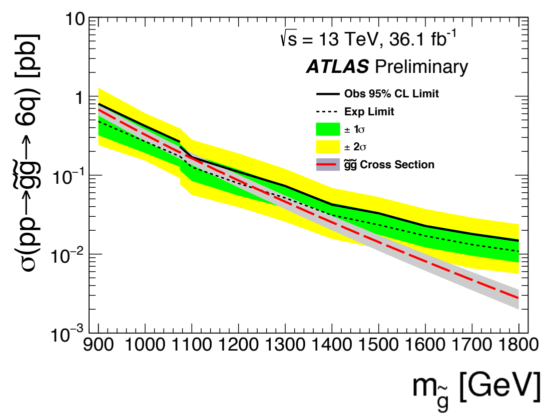
- Search in events with ≥4 large R jets with large $M_J^\Sigma = \sum_{\substack{p_T > 200\,\text{GeV} \\ |\eta| \le 2.0}} m^{\text{jet}}$ [1-3]
- Data-driven background modeling from templates with $n_{\text{jets}} < 4$









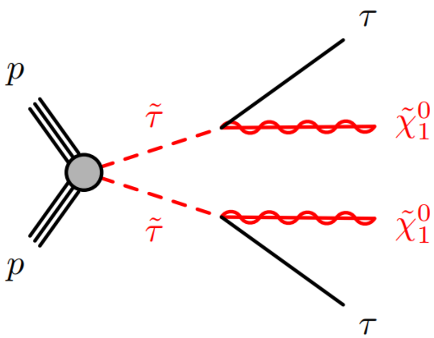


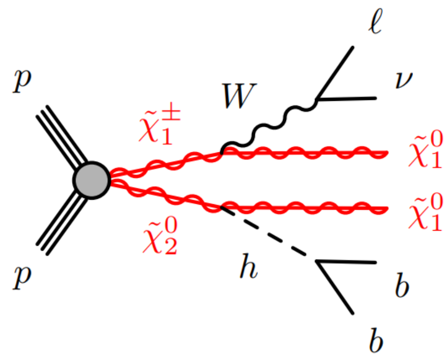
[1] Hook et al., JHEP 3 9, 2012
[2] Hedri et al., JHEP 08 136, 2013
[3] Cohen et al., JHEP 05 005, 2014

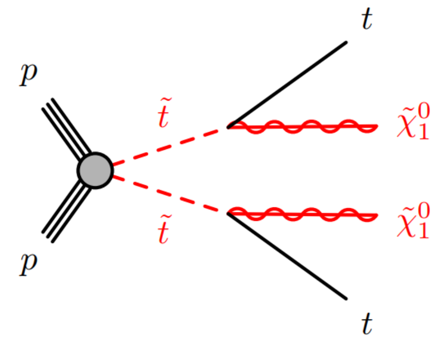
HL-LHC Prospects

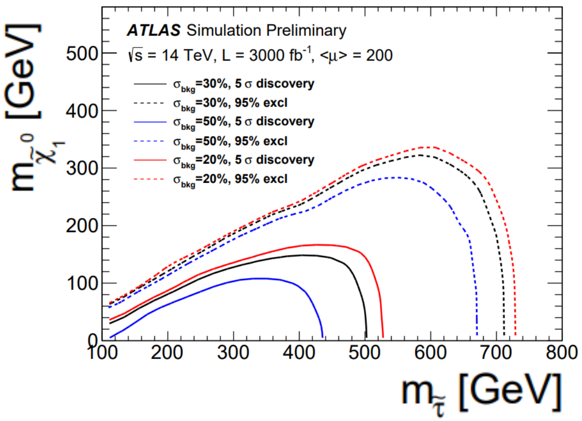
- **Many well-motivated SUSY scenarios require very large lumi**

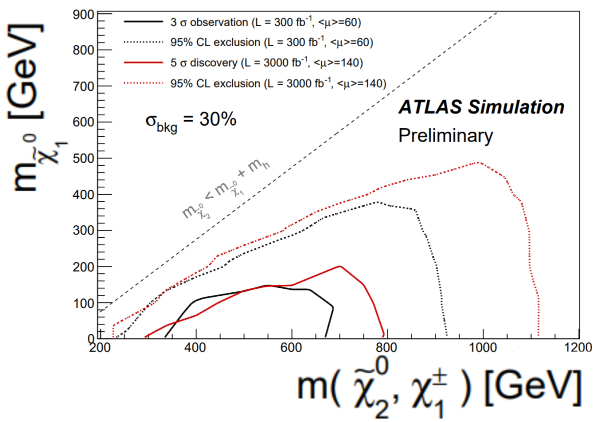
direct staus	**electroweak SUSY with Higgs**	**hidden stops**

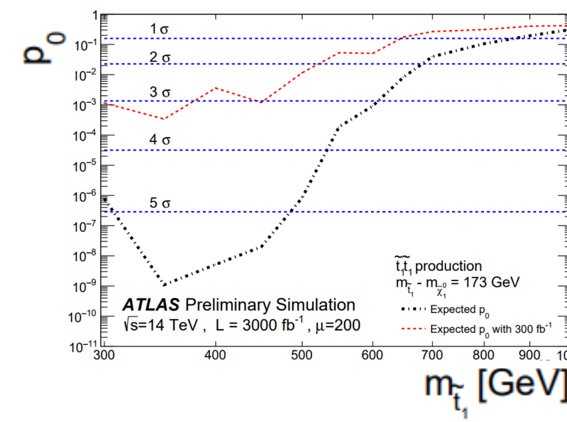








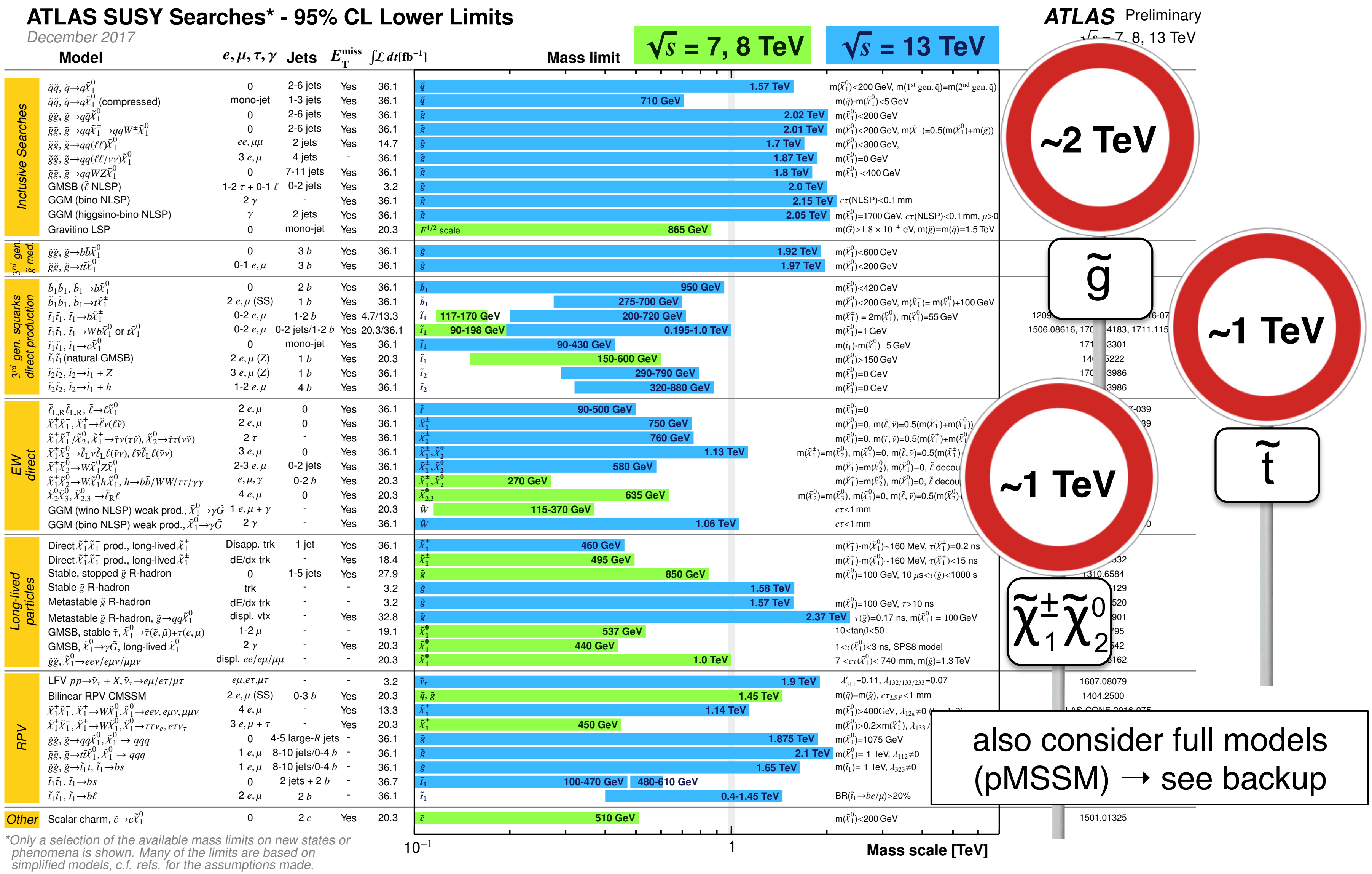




discovery up to ~500 GeV	**discovery up to ~800 GeV**	**discovery up to ~500 GeV**

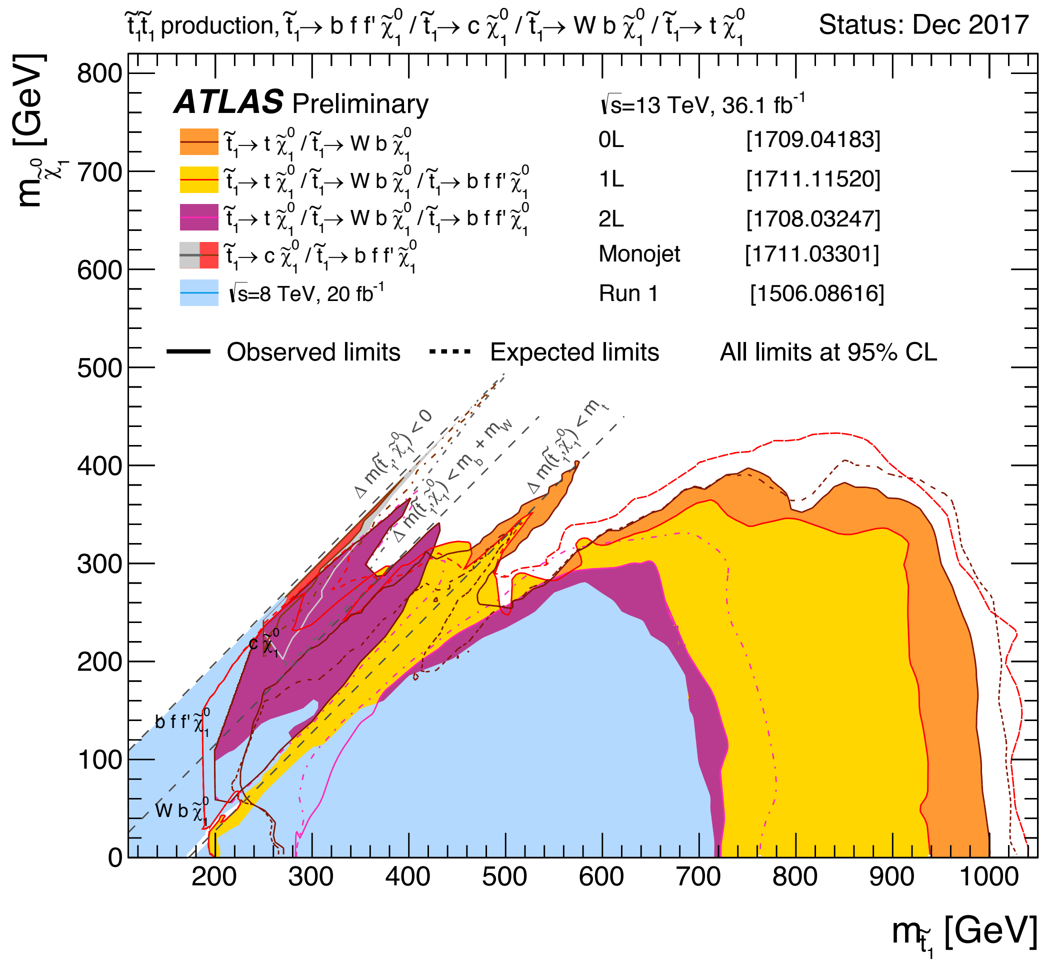
see parallel talk:
Rachel Rosten: New physics at HL-LHC

ATLAS SUSY Grand Summary



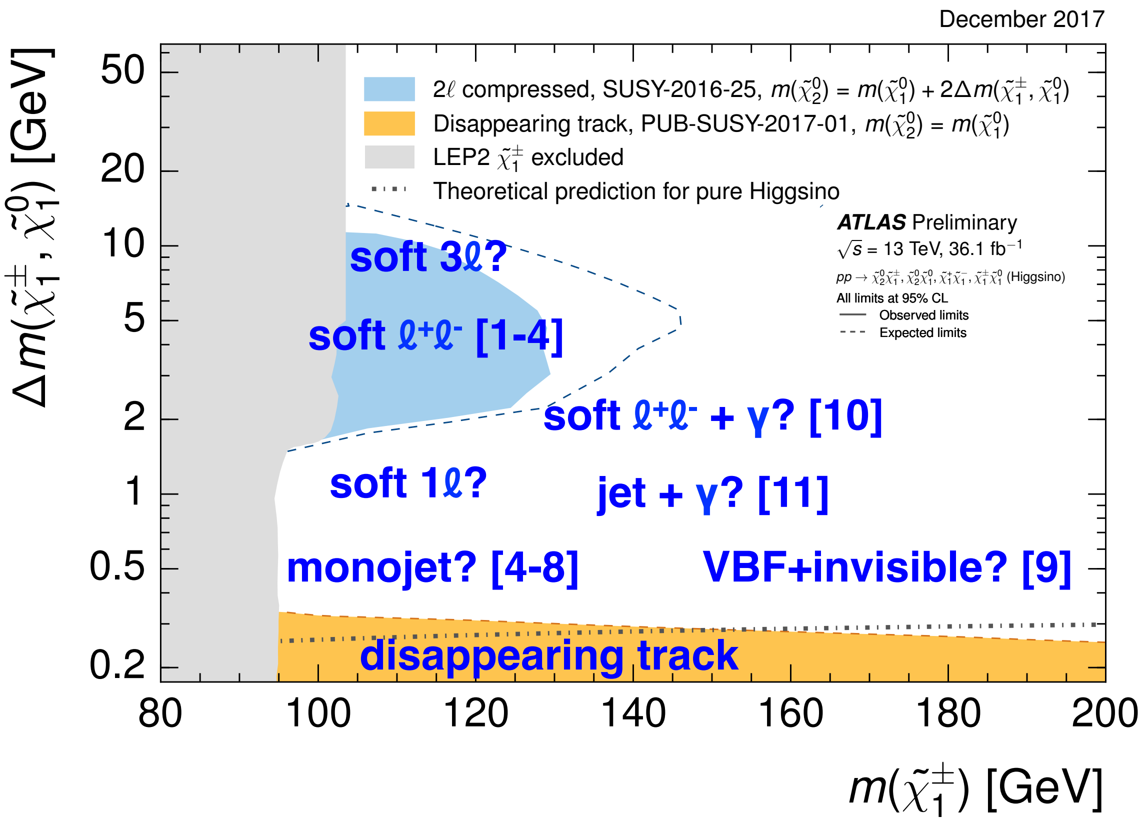
also consider full models (pMSSM) → see backup

Stop Program



- Product of collaboration between theorists and experimentalists and many physicist-centuries of dedicated efforts

Toward a Comprehensive Higgsino Program…



theory / exp. challenges:

- New channels, variables, techniques
- Improving soft lepton efficiency & background rejection
- Reducing systematic uncertainties on fake leptons
- Reducing thresholds using multi-object triggers

[1] Giudice, Han, Wang, and Wang, PRD 81 115011, 2010
[2] Rolbiecki and Sakurai, JHEP 10 071, 2012
[3] Han, Kribs, Martin, and Menon, PRD89 7, 075007, 2014
[4] Schwaller and Zurita, JHEP 03 060, 2014
[5] Han, Kobakhidze, Liu, Saavedra, Wu, Yang, JHEP 02 049, 2014
[6] Baer, Mustafayev, Tata, PRD 89 055007, 2014 and PRD 90 115007, 2014
[7] Low and Wang, JHEP 1408 161, 2014
[8] Barducci, Belyaev, Bharucha, Porod, Sanz, JHEP 1507 066, 2015
[9] Nelson, Tanedo, Whiteson, PRD93, 115029, 2016
[10] Bramante, Delgado, Elahi, Martin, Ostdiek, PRD90 9 095008, 2014
[11] Ismail, Izaguirre, Shuve, Phys. Rev. D 94, 015001, 2016

Summary

- We haven't found SUSY (yet)
- But we have some new ideas, updates, and improvements
  - Exploiting IBL for long-lived particles
  - Recursive Jigsaw Reconstruction for difficult regions of parameter space
  - Reduced lepton p_T thresholds for compressed searches
- And some interesting new territory to explore with them…

Additional Material

Do You Want to Know More?

ATLAS SUSY parallel talks
https://indico.tifr.res.in/indico/conferenceTimeTable.py?confId=5736

Speaker	Topic
Koichi Nagai	all-hadronic squarks & gluinos
Tova Ray Holmes	leptonic squarks & gluinos
Lawrence Lee	RPV / long-lived squarks & gluinos
Francesca Ungaro	RPV / long-lived stops
Sara Kristina Strandberg	stops and sbottoms
Antonio Miucci	stops with τ, Z, h
Ian Michael Snyder	pMSSM
Christian Sander	gauginos and sleptons
Joseph Reichert	higgsinos
Alexander Mann	GMSB
Kouta Onogi	reconstruction techniques

all ATLAS SUSY results are summarized at:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Summary of New Results for SUSY17

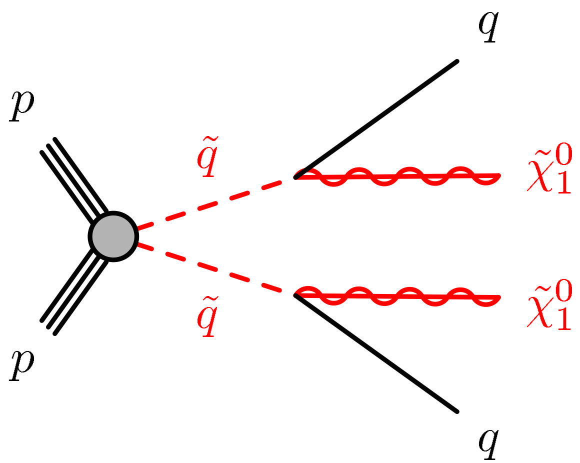
Search	Final State	Limits	References
compressed higgsino LSPs	soft e^+e^- / $\mu^+\mu^-$ + jet(s) + MET	$\mu > 110$ (130) GeV for $\Delta m(\chi_2, \chi_1) = 3$ (6) GeV	SUSY-2016-25
compressed slepton NLSPs	soft $\ell^+\ell^-$ + jet(s) + MET	$m_\ell > 100$ (180) GeV for $\Delta m(\ell, \chi_1) = 2$ (4) GeV	
GMSB higgsino NLSPs	4b + MET	exclude μ between 130-230 GeV and 290-880 GeV for BF(h→ h G) = 1	ATLAS-CONF-2017-081
ultra-compressed higgsinos	disappearing track + jet + MET	exclude chargino masses up to 152 GeV	ATL-PHYS-PUB-2017-019 (reinterpretation of ATLAS-CONF-2017-017)
GMSB with photons	γ / γγ + MET	max. reach up to 1.2 TeV charginos/neutralinos	ATLAS-CONF-2017-080
stop→stau	2ℓ + MET (+ jets)	1160 GeV	ATLAS-CONF-2017-079
mono-jet	jet + MET	$\sigma_{SD} \sim 10^{-43}$ cm^2, $m_{mediator} \sim 1.6$ TeV (axial-vector/vector)	1711.03301
DM+HF	b-jets + MET	$m_{mediator} \sim 1.1$ TeV	1710.11412
RPV multijets	≥4 jets	$m_{gluino} \sim 1.9$ TeV	SUSY-2016-22

ATLAS SUSY(-like) “Excesses”

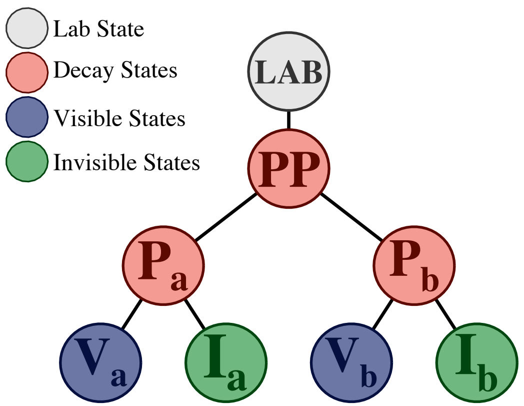
Search	Significance	Signal Region: Selection	References
multi-b	2.5σ	SR-0L-HH: ≥3 b-jets, ≥6 jets, MET > 400 GeV, m_{eff} > 2.5 TeV	1711.01901
γ / γγ + MET	2.4σ	SR_{L200}: ≥1γ, ≥5 jets, MET > 200 GeV, m_{eff} > 2 TeV	ATLAS-CONF-2017-80
SS $\mu\mu$ + b-jets*	ttH $\mu_{sig} = 3.5^{+1.7}_{-1.3}$	SS $2\ell+1\tau_{had}$ + b-jets	ATLAS-CONF-2017-77

Aside: Recursive Jigsaw Reconstruction

target signal process



assumed decay chain



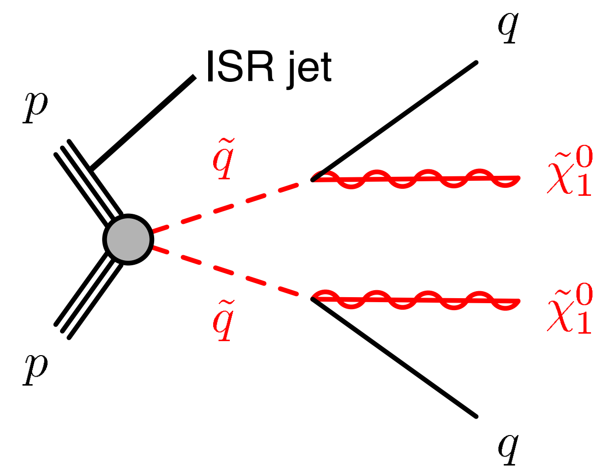
- Razor [1] → Super-Razor [2] → **Recursive Jigsaw Reconstruction (RJR) [3]**
- Novel method for **reconstructing** final states assuming a specific decay chain
- Perform **recursive** series of Lorentz boosts to transform between frames, using **jigsaw** rules to specify unknown degrees of freedom
- Obtain **complete set of useful variables** *diagonalized* with physical observables: angles, energies, masses, etc
- Code from Paul Jackson and Chris Rogan available at http://restframes.com/

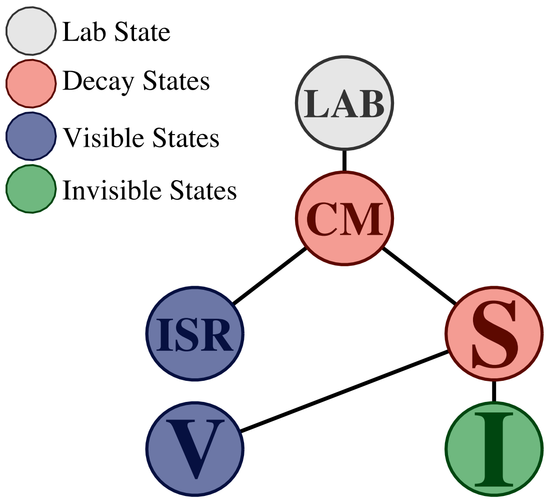
[1] Rogan, "Kinematical variables towards new dynamics at the LHC", arXiv:1006.2727 [hep-ph], CALT-68-2790
[2] Buckley, Lykken, Rogan, Spiropulu, "Super-razor and searches for sleptons and charginos at the LHC," PRD 89 (2014) 055020
[3] Jackson, Rogan, Santoni, "Sparticles in Motion - getting to the line in compressed scenarios with the Recursive Jigsaw Reconstruction," PRD95 (2017) 035031

Aside: RJR for Compressed SUSY

- Need to separate jets from SUSY decays (**V**) from recoil system (**ISR**)
- Apply jigsaw rule based on minimization of masses in estimated CM frame:

$$M_{CM} = \sqrt{M_{ISR} + \left(p_{ISR}^{CM}\right)^2} + \sqrt{M_S + \left(p_S^{CM}\right)^2}$$





Jackson, Rogan, Santoni, PRD95 (2017) 035031

Aside: RJR for Compressed SUSY

- Need to separate jets from SUSY decays (**V**) from recoil system (**ISR**)
- Apply jigsaw rule based on minimization of masses in estimated CM frame:

$$M_{CM} = \sqrt{M_{ISR} + \left(p_{ISR}^{CM}\right)^2} + \sqrt{M_S + \left(p_S^{CM}\right)^2}$$

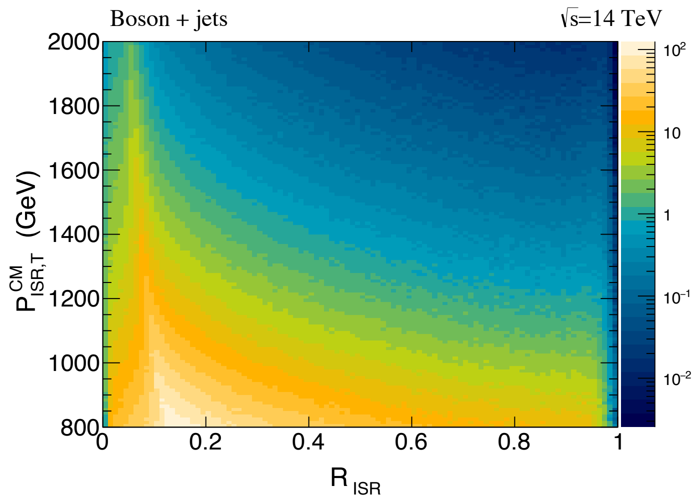
- Reconstruct S vs. B discriminants in CM frame, e.g.:

$$R_{\mathrm{ISR}} \equiv \frac{|\vec{p}_{\mathbf{I},T}^{\,\mathbf{CM}} \cdot \hat{p}_{\mathbf{ISR},T}^{\,\mathbf{CM}}|}{|\vec{p}_{\mathbf{ISR},T}^{\,\mathbf{CM}}|} \sim \frac{E_T^{\mathrm{miss}}}{p_T^{ISR}} \sim \frac{m_{\tilde{\chi}}}{m_{\tilde{q}}}$$

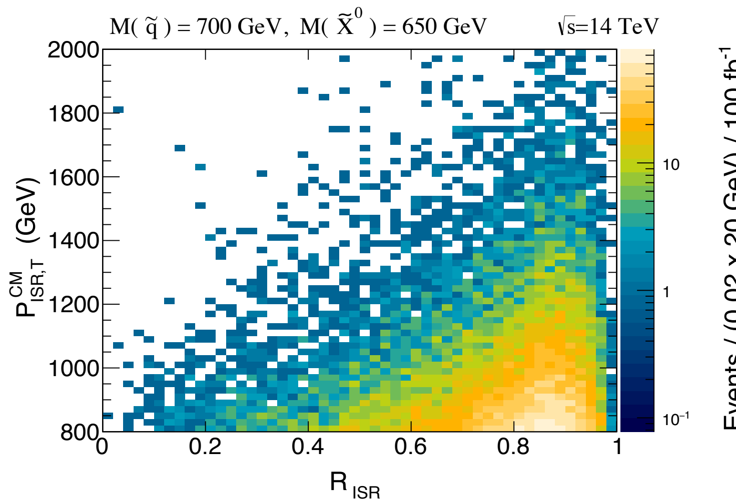
$p_{\mathbf{ISR},T}^{\mathbf{CM}}$ = vector sum p_T of ISR jets

- Exploit different correlations for S vs. B

background (V+jets)

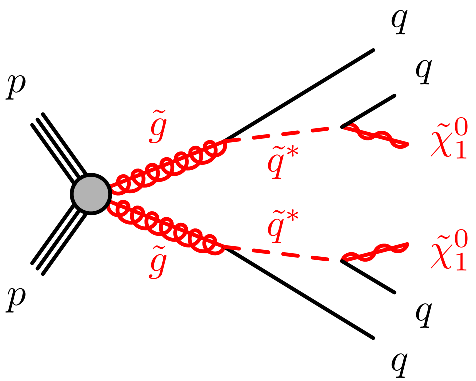


signal (squark → q LSP)



Jackson, Rogan, Santoni, PRD95 (2017) 035031

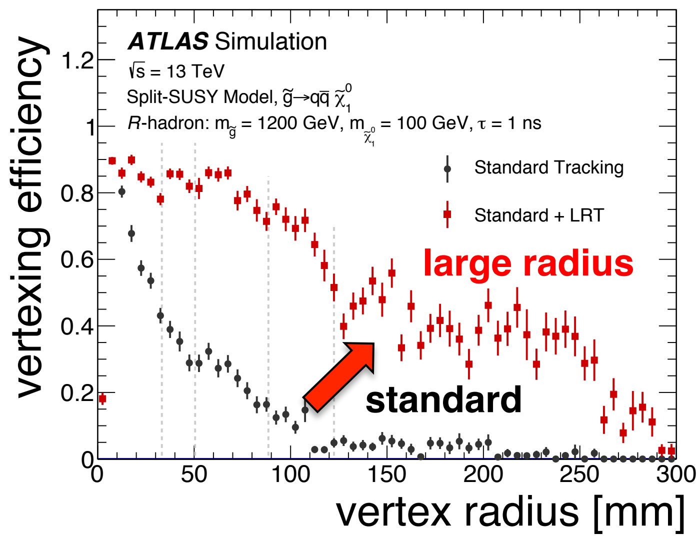
Displaced Vertex Search

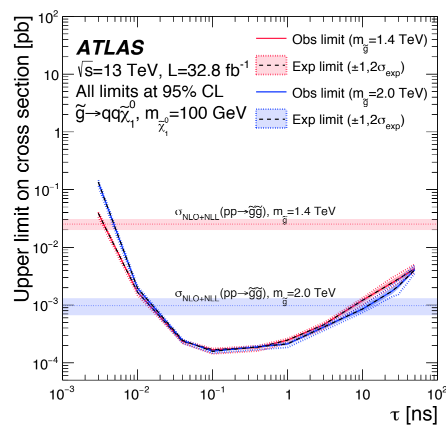


- **Search for long-lived particles from:**
  - Gluino decays with very massive quarks (e.g. split SUSY [1,2]), hidden valley models [3], RPV SUSY [4,5]
- **Signature:**
  - Displaced vertex (R ~ 4-100 mm) with high track multiplicity (≥5) and mass (>10 GeV) + MET

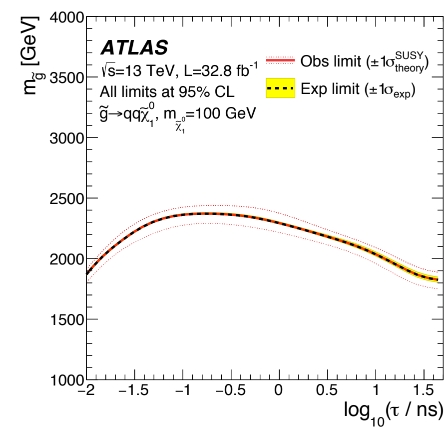
Strategy (specialized algorithms):

- **Tracking:** 2nd pass **Large Radius Tracking** [ATL-PHYS-PUB-2017-014]
- **Vertexing:** find 2-track vertex seeds, merge, discard poorly associated tracks, require R < 30 cm and |z| < 30 cm





(a) Upper limits on production cross section

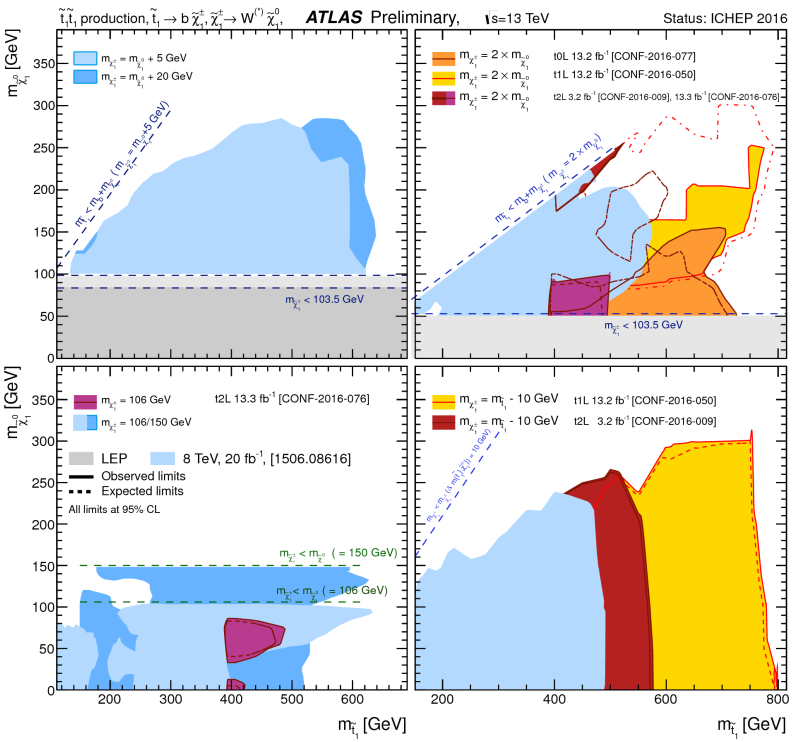


(b) Lower limits on $m_{\tilde{g}}$

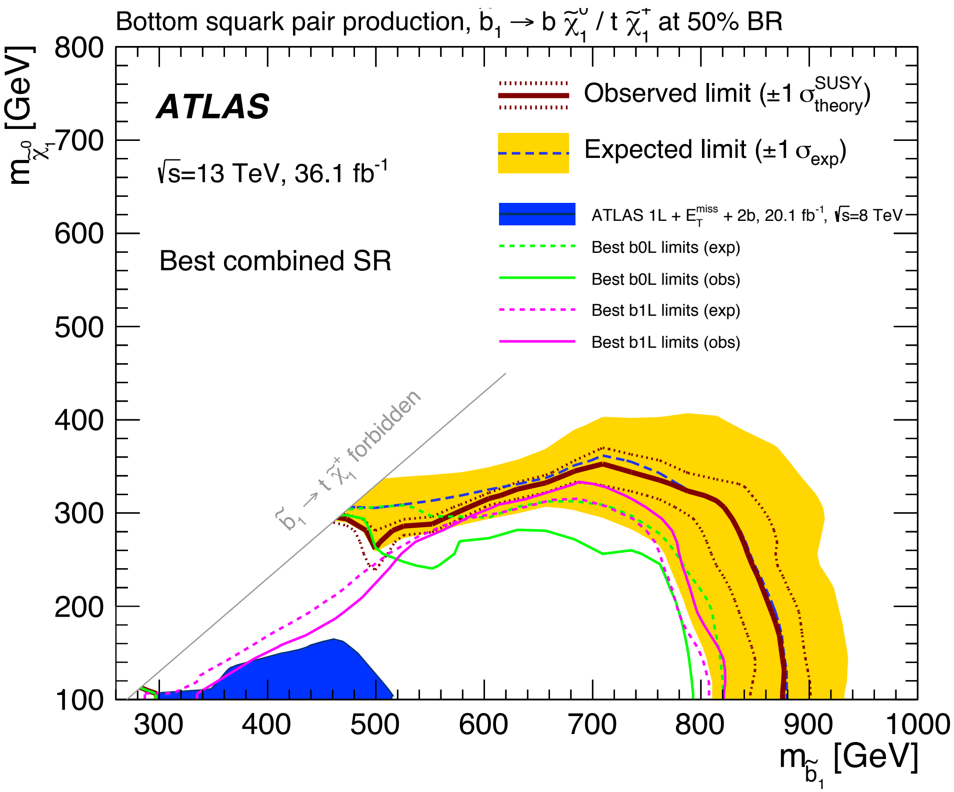
[1] Arkani-Hamed and Dimopolous, JHEP 06 (2005) 073
[2] Guidice and Romanino, Nucl. Phys. B 699 (2004) 65
[3] Strassler and Zurek, PLB 651 (2007) 374
[4] Barbieri et al., Phys. Rept. 420 (2005) 1
[5] Allanach et al., PRD75 (2007) 035002

Additional Stop Interpretations

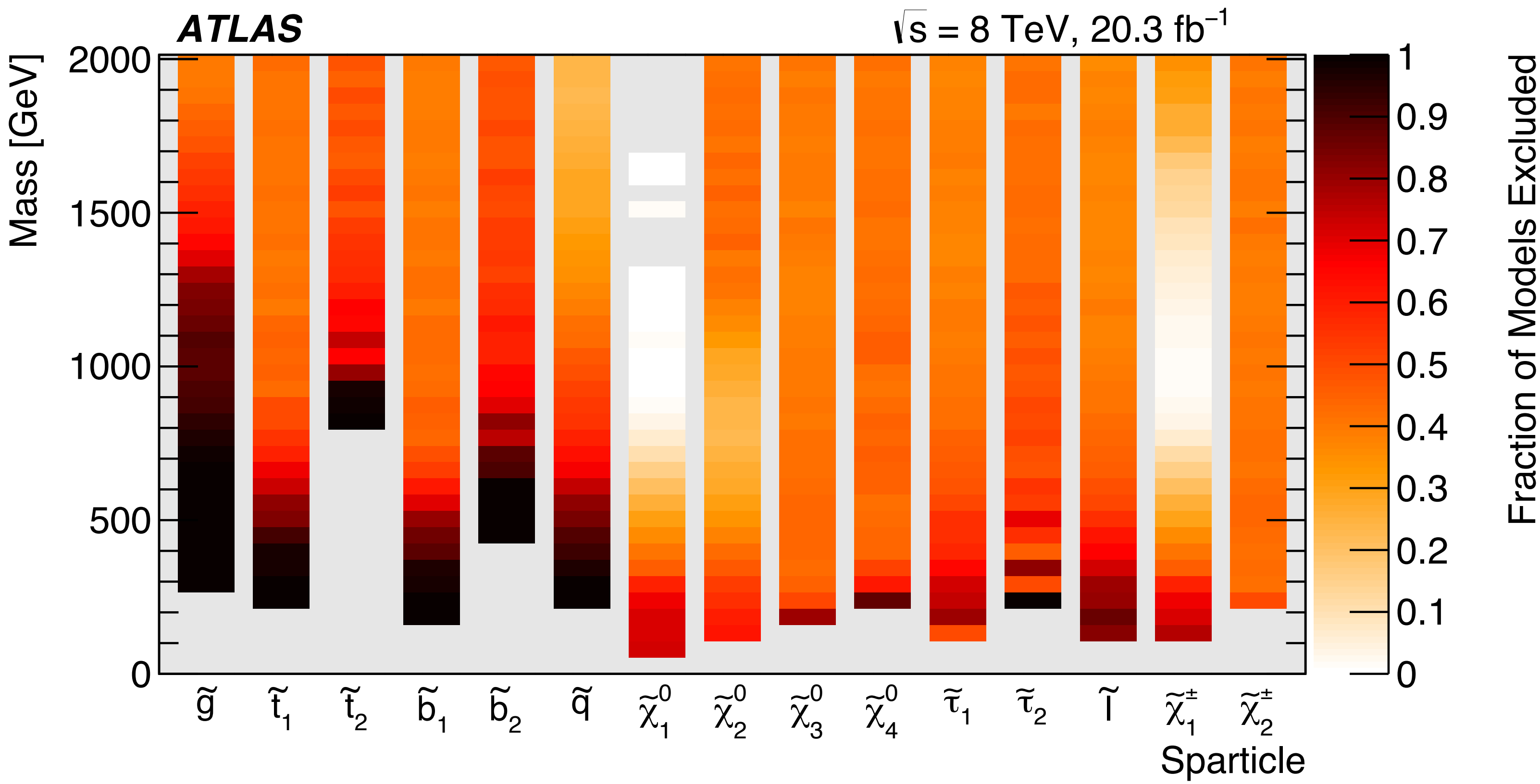
stops



sbottoms



ATLAS SUSY Grand Summary: Full Models (pMSSM)



see parallel talks:
Ian Michael Snyder: pMSSM stop results

Direct Dark Matter Production

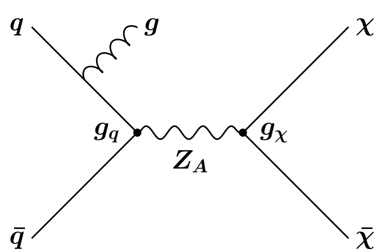
monojet
1711.03301

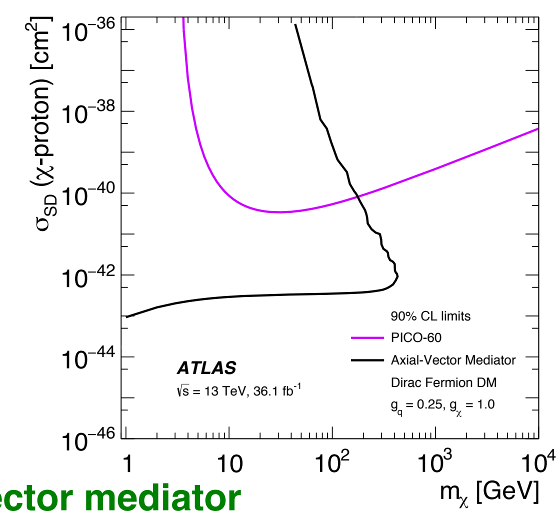
DM+heavy flavor
1710.11412

- Search for high p_T jet + MET, no leptons
- Most sensitive to (axial-)vector mediators → stringent constraints* on spin-dependent DM

- Search for bb+E_T^{miss}, tt+E_T^{miss}, b+E_T^{miss}
- Starting to probe (pseudo-)scalar mediators!

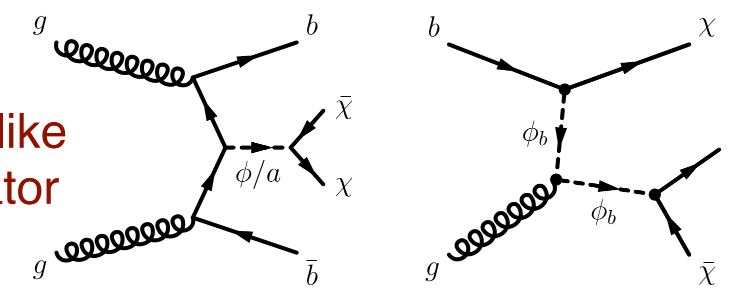
Z-like mediator

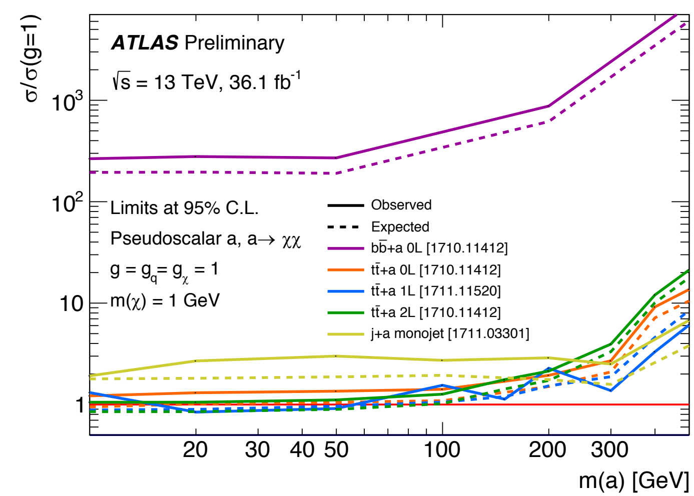




*axial-vector mediator

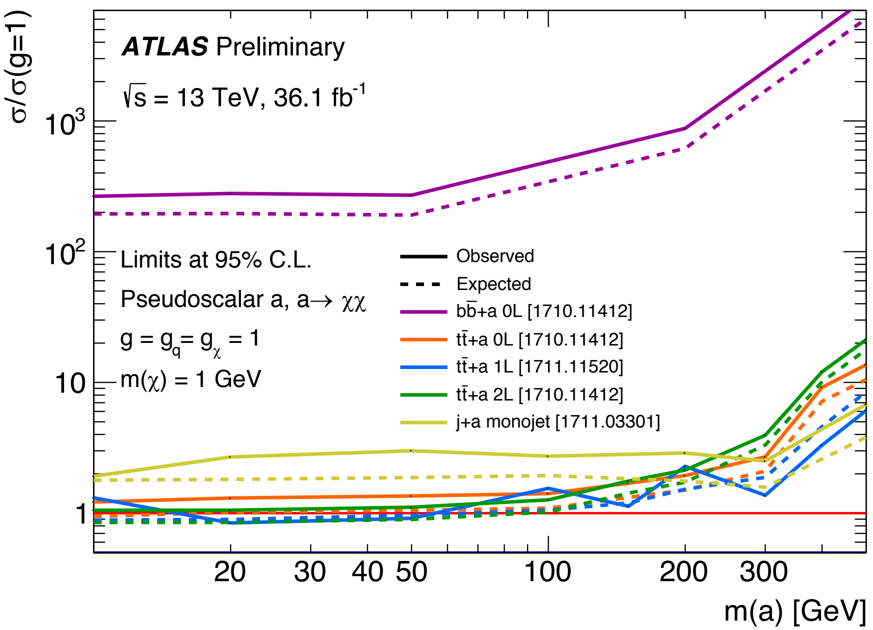
higgs-like mediator



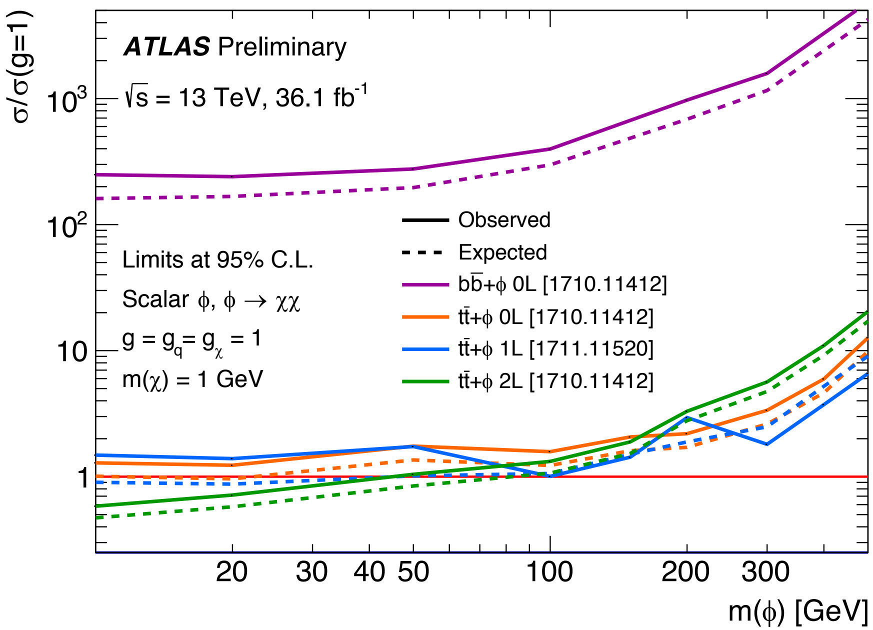


Summary of Dark Matter Searches

pseudo-scalar mediator



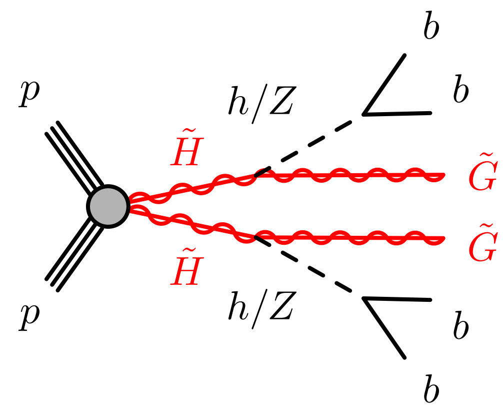
scalar mediator



- Just starting to probe interesting territory for (pseudo-)scalar mediators!

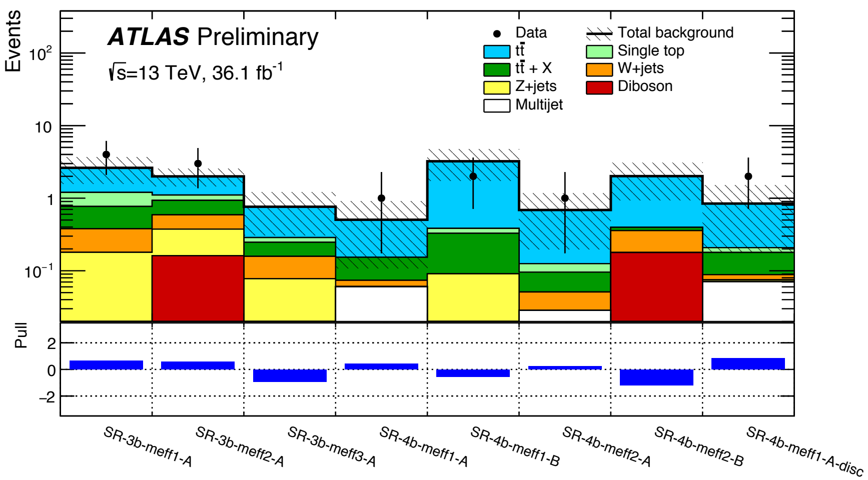
hh / hZ → 4b+MET (high-mass search)

- **Selection**
  - MET triggers
  - 4 jets (≥3 b-jets) + MET > 200 GeV
  - $\Delta\phi(\text{jet}_{1,2,3,4},\text{MET}) > 0.4$ → kill QCD
  - Large m_{eff}, m_T(b,MET) → suppress ttbar



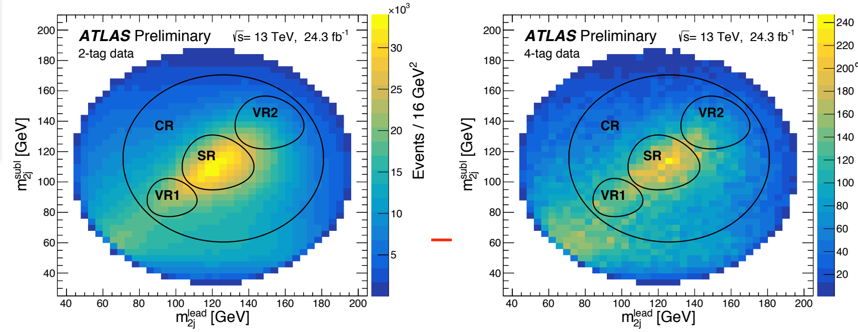
- **Strategy**
  - Group jets into 2 Higgs candidates by minimizing $\Delta R_{max} = \max[\ \Delta R(h_1,)\ ,\ \Delta R(h_2,)\ ]$
  - Extrapolate background in SRs with $m(h_1),m(h_2) \sim m_{higgs}$ from from CRs with inverted Higgs mass cuts

- **Results**
  - Data consistent with background (7 overlapping exclusion SRs + discovery SR)
  - Exclude μ 230-880 GeV for BF($\tilde{h} \rightarrow h\,\tilde{G}$) = 1



Scenario 1: GMSB higgsino NLSPs
hh / hZ ➞ 4b+MET (low-mass search)

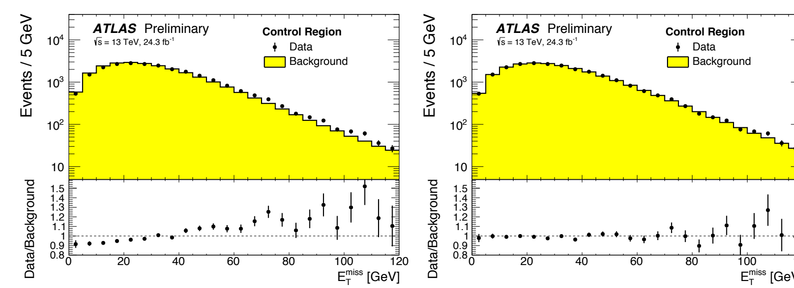
Extend sensitivity to low-mass higgsinos using b-jet triggers (extension of ATLAS di-Higgs search*)



- **Selection**
  - ≥4 b-jets
- **Strategy**
  - Group jets into 2 Higgs candidates by minimizing

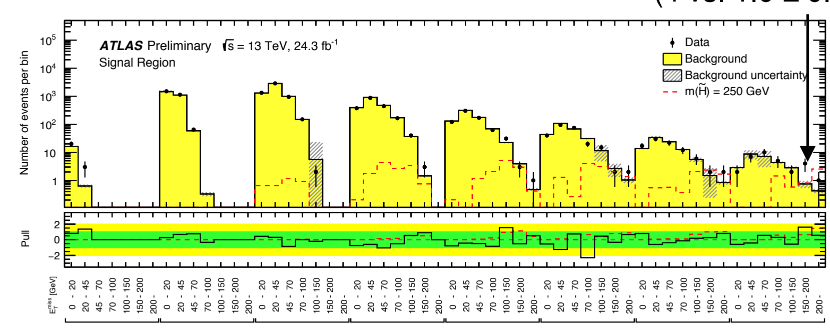
$$D_{hh} = \left| m_{2j}^{\text{lead}} - \frac{120}{110} m_{2j}^{\text{subl}} \right|$$

  - Extrapolate background from 2b CRs ➞ 4b SRs
    - Novel use of BDT for multi-dimensional reweighting (add backup slide)



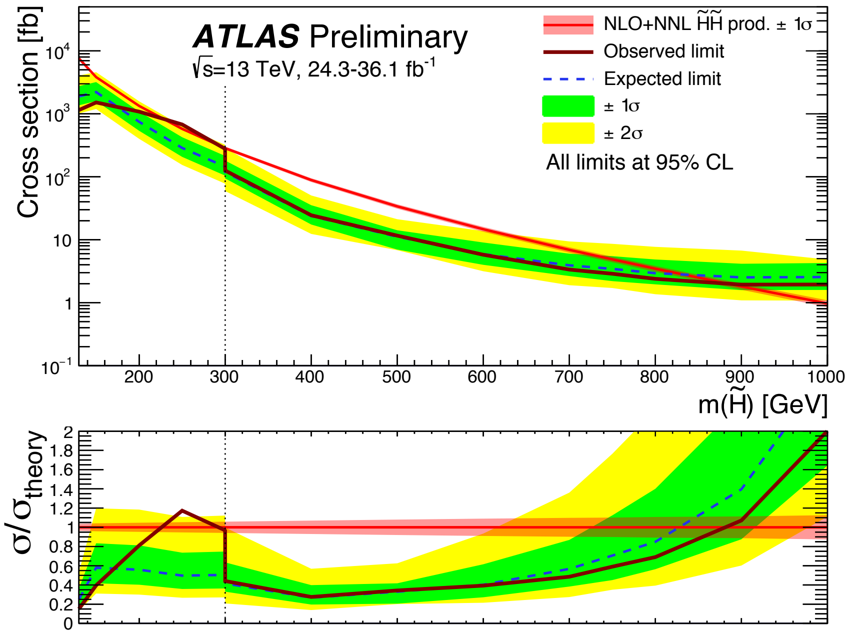
- **Results**
  - Data consistent with background in 56 exclusive bins of (MET,m_{eff}) + 2 discovery SRs
  - Exclude μ 130-230 GeV for BF($\tilde{h}$ ➞ h $\tilde{G}$) = 1

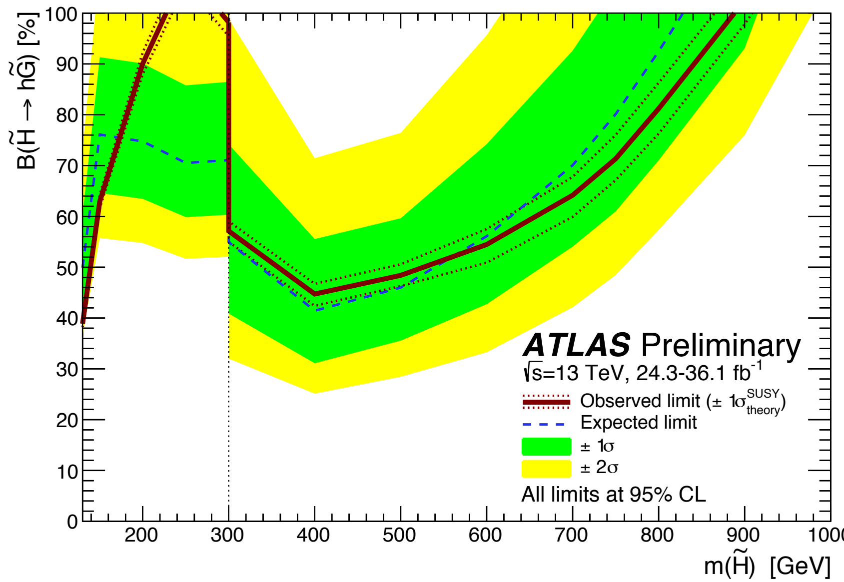
max. excess (4 vs. 1.0 ± 0.2)



*see talk Elizabeth Brost

Scenario 1: GMSB higgsino NLSPs
Interpretations





Higgsino Search: Additional Interpretations